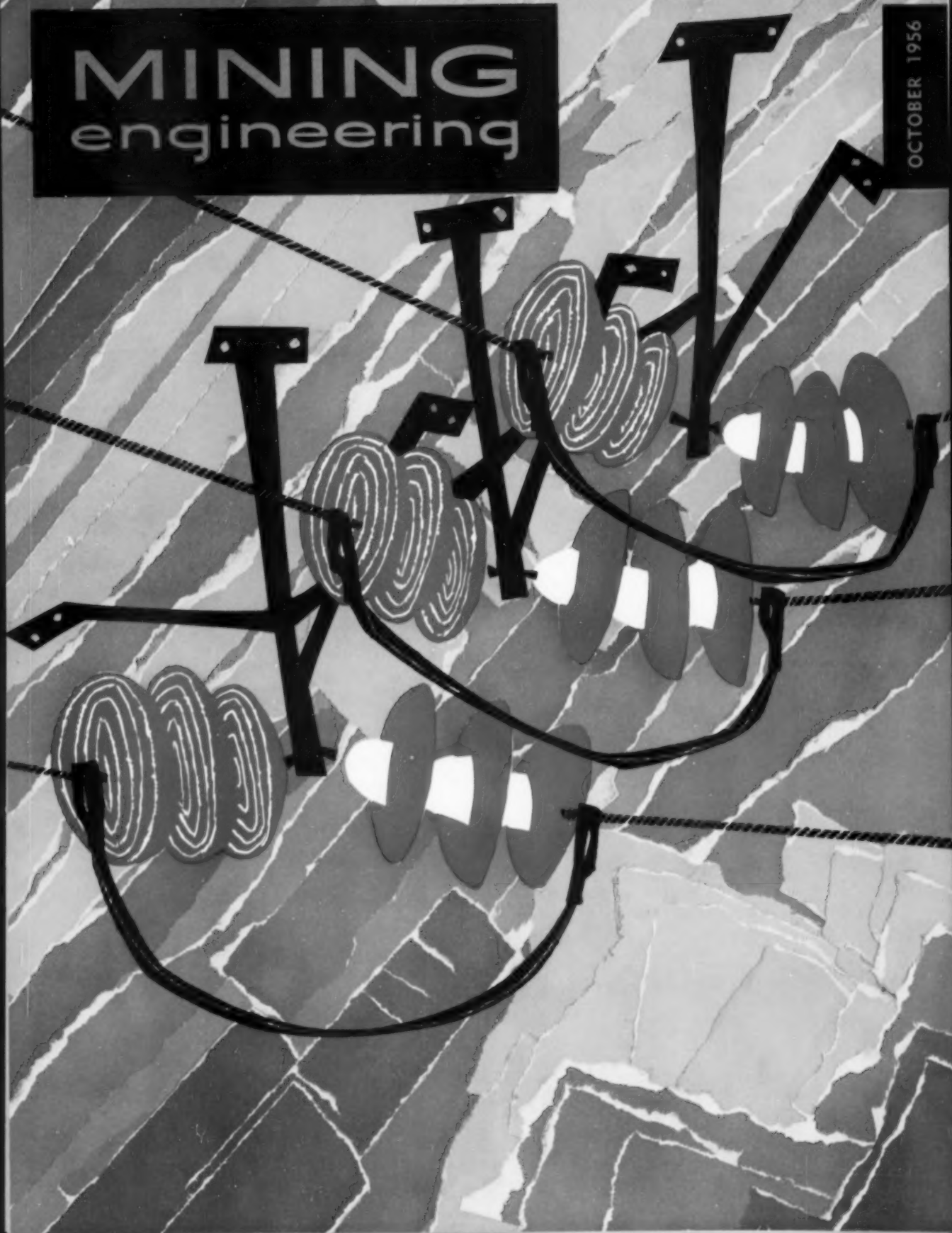
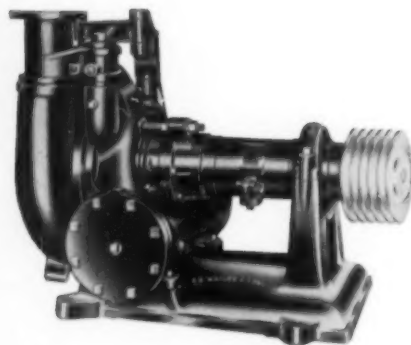


# MINING engineering

OCTOBER 1956



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**Sand Pumps**  
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# MINING engineering

VOL. 8 NO. 10

OCTOBER 1956

## COVER

Suspension insulators carry high voltage lines underground in this month's cover by artist Herb McClure. One solution to the problem of supplying electric power to a modern mine is given on page 982 of this issue.

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# PERSONNEL

THE following employment items are made available to AIME members on a non-profit basis by the Engineering Societies Personnel Service, Inc. (Agency) operating in cooperation with the Four Founder Societies. Local offices of the Personnel Service are at 8 W. 40th St., New York 18; 100 Farnsworth Ave., Detroit; 57 Post St., San Francisco; 84 E. Randolph St., Chicago 1. Applicants should address all mail to the proper key numbers in care of the New York office and include 6c in stamps for forwarding and returning application. The applicant agrees, if placed in a position by means of the Service, to pay the placement fee listed by the Service. AIME members may secure a weekly bulletin of positions available for \$3.50 a quarter, \$12 a year.

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**PRODUCTION — EXPLORATION**  
**SALES PROMOTION**  
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mining. Registered engineer. Prefer western U. S. M-283-San Francisco.

**Mining Engineer, 41, married, no children, excellent health.** Twenty years experience all types underground mining, exploration, and development. Experience includes mine superintendent, chief engineer, chief draftsman, construction engineer, etc. Speak Spanish. Prefer employment in South or Central America or other tropical areas. Available 30 days. M-285.

**Management or Executive, B.S. in mining engineering, 44.** More than 15 years experience in mining industry; approximately 10 years experience in public relations, sales engineering, contract negotiations, and general business experience. Seven years foreign experience. Speak Spanish well; working knowledge of Portuguese. Own business eight years. M-286.

Mining engineer required as a mine superintendent of an underground gypsum operation. Attractive surroundings and living conditions in the heart of New York State's Finger Lakes Region. Position is of a supervisory nature with a minor amount of engineering required. Mine is completely mechanized with most modern equipment available. Apply stating qualifications, experience, marital status, age, salary expected to The Ruberoid Co., Caledonia, N. Y.

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**Mining Engineer or Geologist, to head an exploration and development program in South America.** Should have five to ten years practical engineering experience. Principal interest of company is in barytes ore. Should speak Spanish. Salary, from \$10,000 a year, depending on ability and experience. F3919.

**Geologist, M.S. or Ph.D., with five to ten years experience in structural and/or sedimentary fields, to make special regional and detailed geological studies for nonmetallics.** May be required to do or supervise photogeological, geophysical, and geochemical work in addition to field  
(Continued on page 956)

**METALLURGIST** wanted by Northwest phosphate company to take over operation of beneficiation pilot plant and carry through this work to full-scale plant operation. Salary open.

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## THE RIO TINTO GROUP

The Senior Mining Engineer and Technical Executive for the Rio Tinto Group will be retiring next year.

The Group are seeking as his successor a Senior Mining Engineer of the highest qualifications and standing in the profession, to advise on all technical matters and to coordinate the technical work of the Group.

Candidates should preferably be between 40 and 50 years of age and certainly not more than 55. Applications should be sent to the Secretary, Rio Tinto Management Services (U.K.) Limited, Barrington House, Love Lane, London, E.C.2., in time to be delivered not later than 30th November, 1956.



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Electric Excavators*

**KEEP COSTS DOWN . . . KEEP OUTPUT UP**

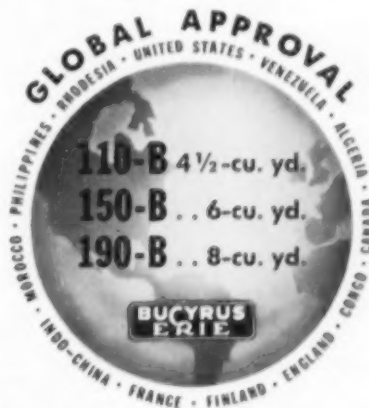


Bucyrus-Erie Ward Leonard electric excavators are helping coal operators everywhere with their modernization plans to boost output while cutting costs. For example, the 150-B shown above is loading unshot coal for the Sunnyhill Coal Co., near Lexington, Ohio.

These modern machines are designed to meet today's production problems. The front end has plenty of strength without dead weight—material can be moved with less effort and power consumption. Ward Leonard control provides rapid acceleration and deceleration to help achieve high-speed digging

cycles. There is plenty of extra torque and ample usable power when most needed.

Plan to bring the advantages of these modern shovels to your operations. 91136



*Bucyrus-Erie Company*

South Milwaukee, Wisconsin

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helps you achieve  
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and cleanliness  
in your plant



Norblo has developed bag type dust collection systems to a high degree of efficiency.

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For continuous and heavy duty service at constant capacity and efficiency, Norblo Automatic Bag Type collection pays its own way — in recovery of valuable materials or removal of injurious or "nuisance" industrial air contaminants. Norblo builds the entire installation, from blowers to bag-cleaning mechanisms. Complete systems are engineered to meet specific situations. Norblo engineering insures low maintenance and no shut-downs — guarantees performance of every installation.

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Based on the same construction principles, the standard bag type collectors provide at low cost the high efficiency service that is obtainable only from bag-type cloth filtering, with either compressed air or electrically driven periodical bag shaking and cleaning. Units must be shut down for cleaning — at such times as the noon hour and end of working day.



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For excellent results in localized dust control, Norblo Portables protect equipment and reduce maintenance in grinding, polishing and cutting departments. Six models cover capacities from 300 to 1350 cfm., at 8" static pressure at the fan. Occupy small space. Are unusually quiet.

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given whenever possible.

**Geology and Ourselves**, by F. H. Edmunds, *Philosophical Library*, \$10.00, 254 pp., 1956.—An illustrated general survey of the economic applications of geology, this book introduces the subjects of geophysics, geochemistry, and soil-mechanics to the layman, and includes chapters on the relation of geology to mining and prospecting.

**Engineering in History**, by R. S. Kirby, S. Withington, A. B. Darling, and F. G. Kilgour, *McGraw-Hill Book Co.*, \$8.50, 530 pp., 1956.—The combined efforts of engineers and historians have produced this survey of engineering from 6000 B.C. to the present which is a general introduction to the subject rather than a definitive history.

**Peaceful Uses of Atomic Energy**, Vol. 8: Production Technology of the Materials used for Nuclear Energy, *United Nations Publications*, \$10.00, 627 pp., 1956.—This collection, a part of the proceedings of the International Conference on the Peaceful Uses of Atomic Energy, is devoted to details of chemical and metallurgical processes for nuclear materials. It is grouped into conference sessions on the treatment of uranium and thorium ores and ore concentrates, the production of metallic uranium and thorium, analytical methods in raw material production, and production technology of special materials.

Please Order These Publications  
from the Publishers

**Mining and the Arts Through the Ages**, *Société de l'Industrie Minière*, \$14.00, 1956.—This volume, containing reproductions of art works inspired by mining from antiquity to the present time, has been issued in commemoration of the centenary mining meeting of La Société de l'Industrie Minière held in Paris last June. The English edition includes a foreword and 11 x 15 in. prints on loose plates, 16 of which are in color, and more than 40 in black and white. The book may be obtained from Mr. M. N. Barbier, c/o French Mining Equipment, 35 Wisconsin Circle, Chevy Chase, Md.

(Continued on page 956)

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...safety!**



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Expanding lineup is simply a matter of adding a starter and connecting the bus. Each starter unit is self-contained.

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Responsibility for assembling proper devices and for control performance rests with Allis-Chalmers.



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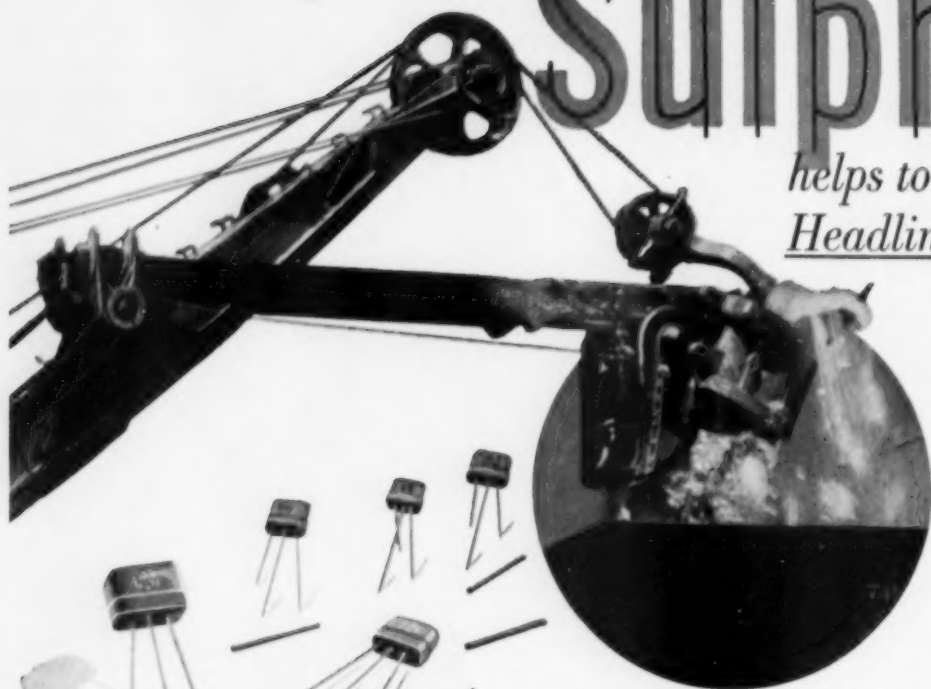
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# Sulphur

*helps to create  
Headline Products*



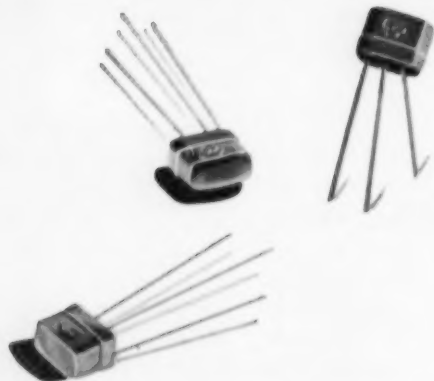
## GERMANIUM

Not too long ago this relatively rare metal was a laboratory curiosity. What to do with it? Today, it's the heart of the tiny transistor—the latest giant of electronics!

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There are two, in fact. One is man-made, involving the routine leaching of Germanium ores with Sulphuric Acid prior to tetrachloride distillation. The other takes advantage of a peculiar property of the natural mineral, Germanium Sulphide. This mineral can be volatilized and then sublimed, providing an effective method of separating the Germanium from gangue material. The process is called "Concentration of Germanium by Sulphide Sublimation".

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# 12 84" WEMCO S-H CLASSIFIERS

chosen by the White Pine Copper Company



One of 12 Wemco S-H Classifiers installed by White Pine Copper Co. at White Pine, Michigan following testing in their company pilot plant. Mining and processing operations for this large project were designed and engineered by the Western Knapp Engineering Company, division of Western Machinery Company.

With annual production of 75 million pounds, White Pine ranks as one of the most important copper projects developed. To serve as a vital part of the primary grinding circuit, White Pine selected twelve 84" Wemco S-H Classifiers. Typical of the magnitude of this project is the fact that these 84" units are the world's largest simplex classifiers.

Six pairs of Wemco S-H Classifiers are operated in closed circuit with six ball mills, 12' 6" x 13' in size. The minerals recovered are chalcocite and minor amounts of native copper occurring in sandstone and shale deposits. Each classifier is of the submerged spiral type of design with 84" double ribbon, variable pitch spiral. Inside tank length totals 41' 9". Operating slope is 3 3/4" per foot.

Each classifier has sand raking loads up to 8000 TPD and overflows feed to flotation at rates up to 1200 TPD. Classifier overflow ranges between 30 and 35% solids (depending on degree of pulp flocculation). Screen analysis of this overflow shows between 2 and 8% plus 100 mesh.

#### Whether your classifier needs are large or small WEMCO DESIGN offers you these METALLURGICAL AND MECHANICAL ADVANTAGES

- **Greater Overflow Capacity** — up to 25% more effective pool area.
- **Greater Raking Capacity** — up to 100% greater sand conveying capacity.
- **Sharper Separation** — less oversize in the overflow and less undersize in the sands.
- **Greater Mechanical Strength** — through Wemco-pioneered large diameter shafts.
- **Balanced Performance** — various models with a wide choice of tanks and spirals achieve correct performance under any condition.
- **Better Drainage** — drier sand for easier conveying and close-circuiting.



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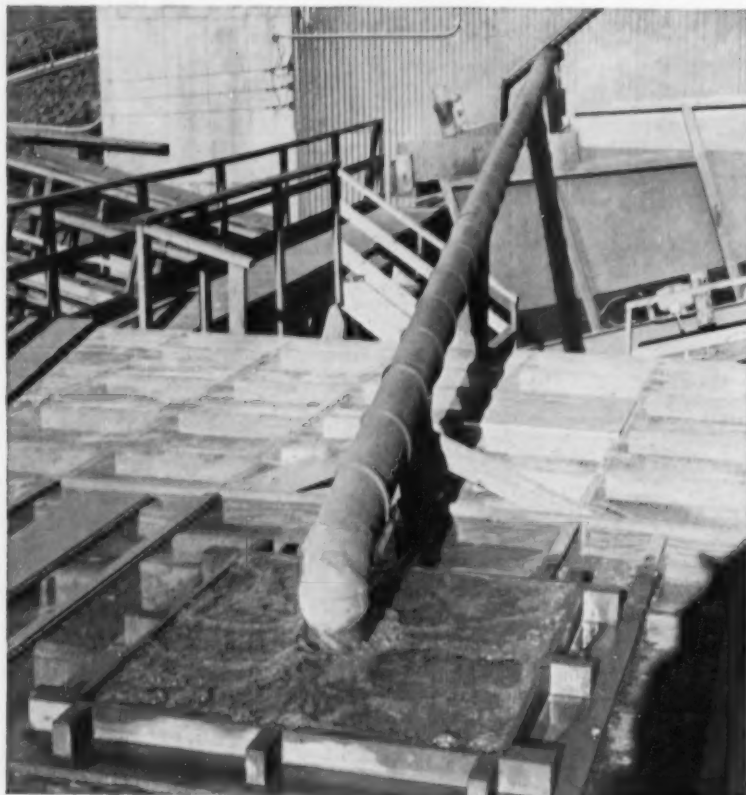


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# NO SECRET

## About **NAYLOR** Performance



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Write for Bulletin No. 507.

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Chicago 19, Illinois

Eastern U. S. and Foreign Sales Office: 350 Madison Avenue, New York 17, New York

956—MINING ENGINEERING, OCTOBER 1956

## BOOKS

(Continued from page 952)

**Metal Statistics 1956**, edited by N. J. Langer, *American Metal Market*, 18 Cliff Street, N. Y. C., \$3.50, 844 pp., 1956.—This 49th annual edition contains a general assortment of statistical information on ferrous and non-ferrous metals. Included are new statistical tables such as titanium ingot and mill product shipments; world production of nickel; refiner's buying prices for copper scrap; consumption of solder in the U. S.; use of tin and lead in solder; manganese ore consumption; electrical conductivity of metals; etc. Statistics dealing with production, consumption, imports, and exports are gathered from such authentic sources as the AISI, USBM, Census Bureau.

### Personnel Service

(Continued from page 950)

and subsurface geological studies. Should speak Spanish; be willing to make occasional trips outside U. S. Location, southern U. S. W3918.

**Assistant or Associate Professor**, mining engineering, to teach mineral dressing and coal preparation and to carry on research in the general field of mineral dressing. Salary and rank dependent upon training and experience. Location, South. W3916.

**Mining Engineer**, with exploration, production, and managerial experience, for small chrome and manganese properties. Salary open. Location, Mediterranean area. F3913.

**Engineers**, to 50, well qualified in the design and planning of new mine plants, laying out projects, and supervising subgroups. Need not be mining engineers but work would be in the mining field. Salaries open. Location, New York. W3911.

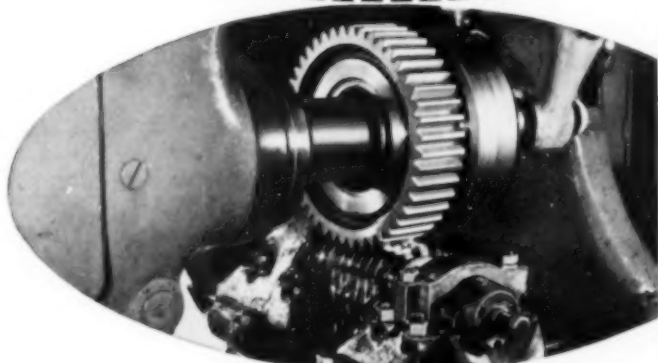
**Mining Engineer**, 30 to 40, preferably single, experienced in reserve estimation and actual mining. Some executive ability desired. Salary, \$6000 a year, plus \$200 a month living allowance. Location, Cuba. F3890.

#### MINING ENGINEER

New, expanding Cuban firm seeks man with some executive ability who is experienced in reserve estimation and actual mining. Relocate in Cuba. Moving expenses. Salary \$500.00, plus \$200.00 living. Prefer single man 30 to 40. Send resume to: Cuba International Mining and Development Corporation, 522 Meadows Bldg., Dallas 6, Texas.

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it pays to use

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1

Skilled craftsmen bring True Original Parts to life—working with the most modern manufacturing equipment and meeting the highest industrial standards. The result: precision-made parts get full work power from your Allis-Chalmers machinery.

## CAREFULLY INSPECTED

2

True Original Parts go through rigid original-equipment inspection and testing processes to assure long-life service. For example, gears are checked again and again for perfect meshing . . . for true balance . . . for full capacity.

## PROPERLY PACKAGED

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You want your parts factory-new . . . and that's how you get True Original Parts. Many are specially treated . . . then sealed and packaged against rust, dust and damage.

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# ALLIS-CHALMERS



# What is the best



## It's GM ... America's First Choice Diesel ... and here's why:

**B**est Diesel for mining—or any other job, for that matter—is the one that does the most work at the lowest cost, above or below ground. That's why General Motors Detroit Diesel engines today handle more different mining jobs than any other Diesel.

These compact, clean-running 2-cycle engines drive loaders, air compressors, draglines, locomotives, pumps, shovels and the most powerful trucks and tractors. GM Diesels are available in more than 1000 different applications of

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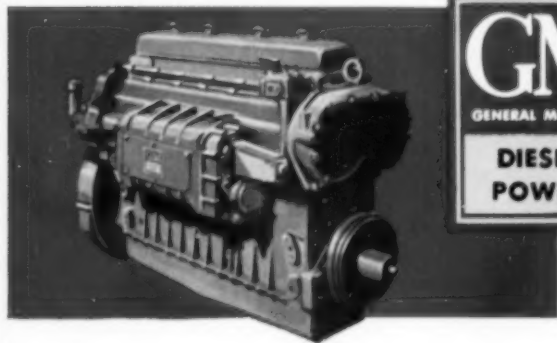
Next time you order new equipment—or re-power old—be sure to specify GM Diesel. It's America's **FIRST CHOICE Diesel** because *it does more work at less cost!*



# Diesel for Mining?



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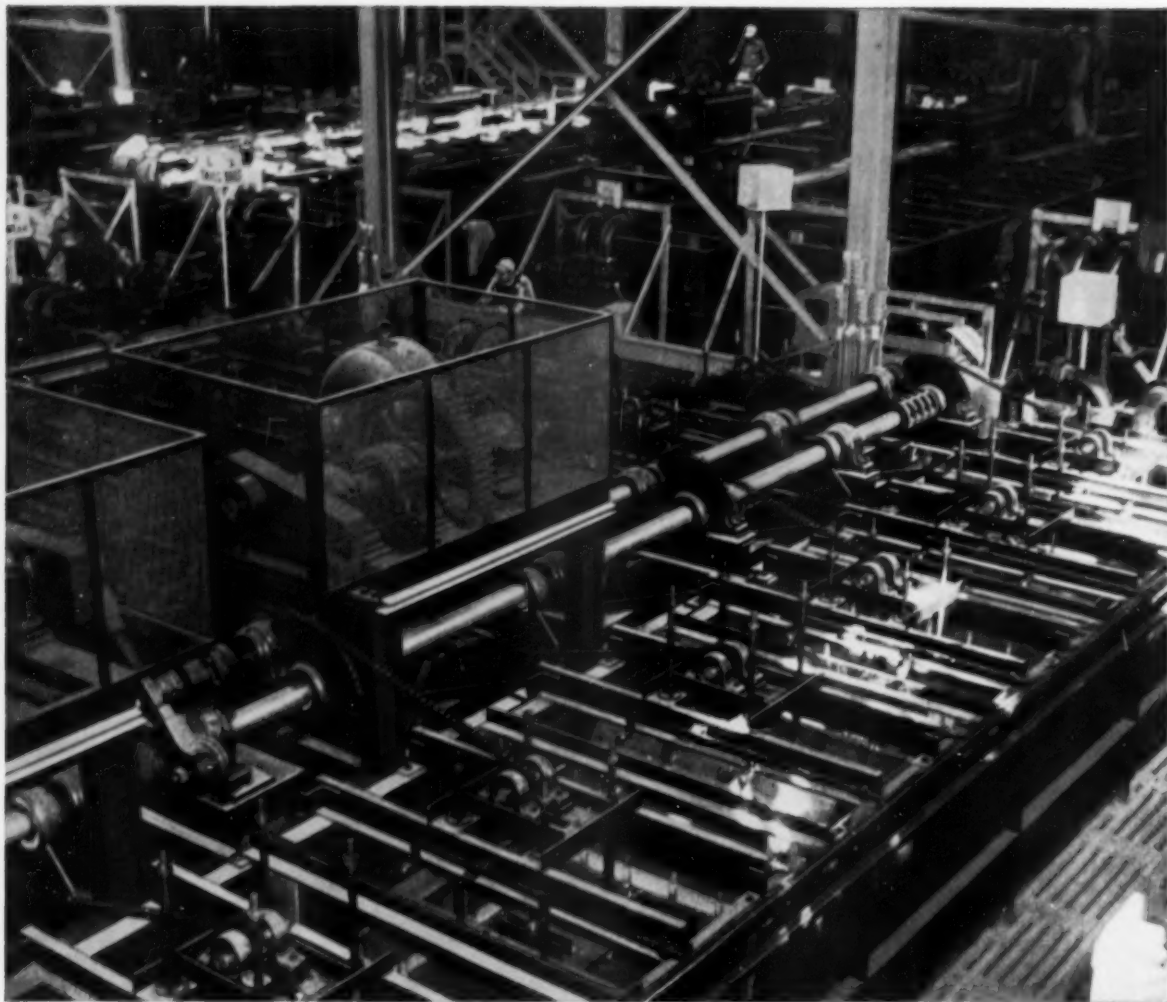
Engine Division of General Motors

Detroit 28, Michigan

In Canada: General Motors Diesel Limited, London, Ontario

Single Engines...30 to 300 H.P. Multiple Units...Up to 893 H.P.

America's Largest Builder of Diesel Engines



## Hydrometallurgy + ion exchange $\rightarrow$ $U_3O_8$

In uranium extraction, the ore, which usually contains from 0.15% to 0.30%  $U_3O_8$ , is first ground and then leached with sulfuric acid or carbonate-bicarbonate solutions to form a slurry or pulp. To avoid costly filtering operations in the acid sections of its plant, mining engineers at Anaconda Company use a new ion exchange technique, "resin-in-pulp," developed by the Atomic Energy Commission. The ore slurry at 4 to 7 percent solids flows through the tanks shown above where stainless steel baskets containing attrition-resistant AMBERLITE ion exchange resins are raised and lowered like giant tea bags. The resin selectively adsorbs up to 99 percent of the uranium as its sulfate complex.

The recovery of uranium is but one way in which AMBERLITE ion exchange resins can serve in hydro-

metallurgy. Rare earth elements can be recovered from complex ores. Dilute wastes from the conventional processing of cobalt and nickel can be scavenged for additional quantities of the metals. Gold can be recovered from cyanide leach liquors. In fact, wherever ions in solutions must be removed or replaced—whether in hydrometallurgy or treatment of water—ion exchange may prove to be the answer. Write for the booklet "Amberlite Ion Exchange Resins," today.

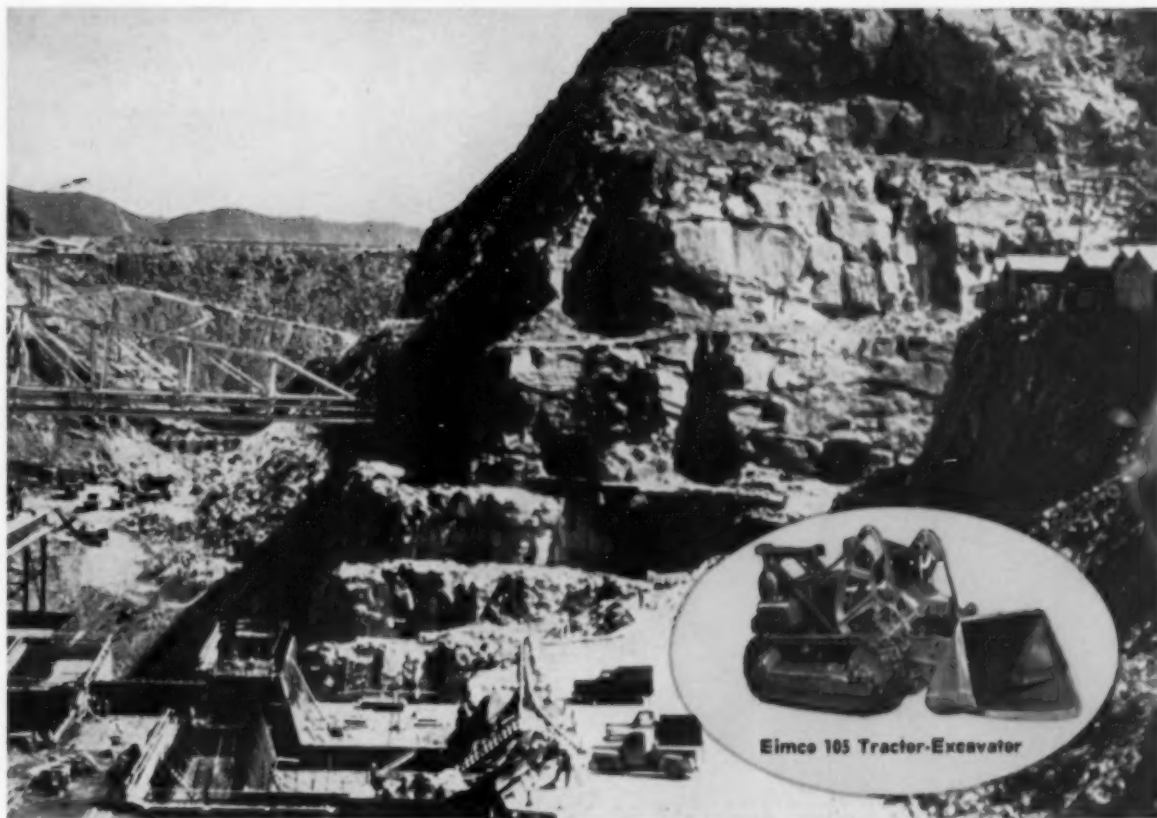


Chemicals for Industry  
**ROHM & HAAS**  
**COMPANY**

THE RESINOUS PRODUCTS DIVISION  
 Washington Square, Philadelphia 5, Pa.

*Representatives in principal foreign countries*

*AMBERLITE is a trademark, Reg. U. S. Pat. Off., and in principal foreign countries.*



## INDIA - EIMCO 105's KEEP GRUELLING SCHEDULE

Two Eimco 105 Tractor-Excavators have each worked 8,000 hours in 12 months to keep progress on schedule at a huge dam project in India.

The machines have received intelligent maintenance and repairs have been small.

**Eimco 105 Tractor-Dozer**



At work on diversion, penstock and highway tunnels, trained Indian crews operating the 105's are doing an excellent job of tunnel driving. In some instances, advance for the size of tunnel being excavated may establish new world records.

"Eimco 105's are preferred equipment to use for tunnels of this type," says one official of a contracting firm. "The transmission, clutches and drive on both machines have not been touched in 8,000 hours of operation. They are in good condition and we expect them to last many more years."

Have you considered why the Eimco 105 is "preferred equipment" to contractors of huge dam, tunnel and road projects in the export market?

It's because their dependability is reflected through their engineered strength to stay on the job around the clock — day in and day out.

The Eimco 105's dependability eliminates the necessity of a sizeable parts depot. Eimco's are built to 100,000 hour standards for service in remote areas. Time saved by Eimco's working continuously with no down time for repairs is a big factor in selecting equipment.

Conditions being equal, Eimco 105's will produce more at less cost and in less time than comparative equipment. Let Eimco show you how this versatile unit can outperform and out-work heavier, more expensive units.

See the Eimco 105 before you buy any crawler tractor equipment.

# THE EIMCO CORPORATION

Salt Lake City, Utah—U.S.A.

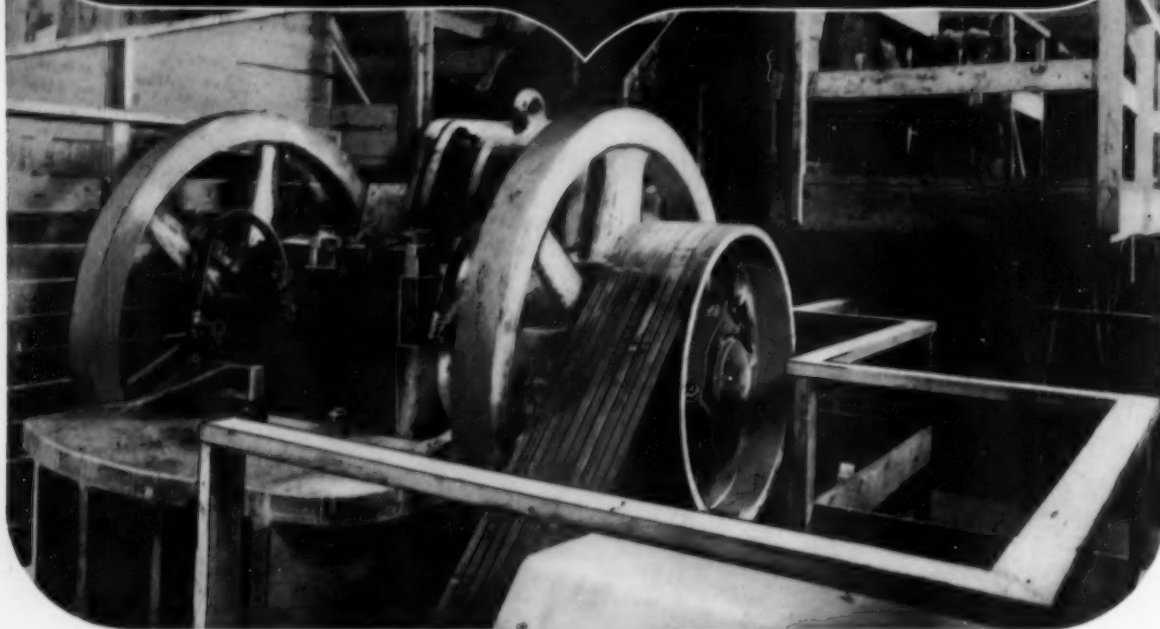
• Export Offices: Eimco Bldg., 52 South St., New York City

New York, N. Y. Chicago, Ill. San Francisco, Calif. El Paso, Tex. Birmingham, Ala. Duluth, Minn. Kellogg, Ida. Baltimore, Md. Pittsburgh, Pa. Seattle, Wash. Cleveland, Ohio Houston, Texas Vancouver, B. C. London, England Goteborg, England Paris, France Milan, Italy Johannesburg, South Africa



B-234

# Traylor ALL STEEL JAW CRUSHERS



## CHOICE OF LEADERS IN THE MINING FIELD FOR HEAVY DUTY PRIMARY CRUSHING SERVICE

For over a half-century, leaders in the mining industry have relied on Traylor Jaw Crushers for profitable primary ore reduction. Traylor Jaw Crushers have earned this universal acceptance by their proven ability to increase production while lowering production costs. Their Traylor designed, non-chokable, curved jaw plates are of manganese steel . . . engineered to provide increased capacity in each succeeding feeding zone in the crushing chamber, thus eliminating packing and choking. Gradual wear is evenly distributed over the entire face of Traylor curved jaw plates. That's why Traylor curved jaw plates often outlast convention-

al plates by as much as 3 to 1. And . . . because the curved plates apply power as a direct crushing force . . . owners of Traylor Jaw Crushers realize greater production from greatly reduced horsepower requirements. Send for Traylor booklet on Jaw Crushers which fully describes all the features that make Traylor Jaw Crushers the choice of leaders in the mining industry.

There's a Traylor Jaw Crusher for every mining need. Traylor builds four different types. Each is built in a wide range of sizes. Feed openings range from 8" x 12" to 60" x 84"; capacities from 4 to 1000 tons per hour.



**TRAYLOR ENGINEERING & MFG. CO.**  
802 MILL ST., ALLENTOWN, PA.

SALES OFFICES: New York • Chicago • San Francisco  
Canadian Mfr: Canadian Vickers, Ltd., Montreal, P.Q.



Primary Gyratory Crushers



Rotary Kilns



Secondary Gyratory Crushers



Ball Mills



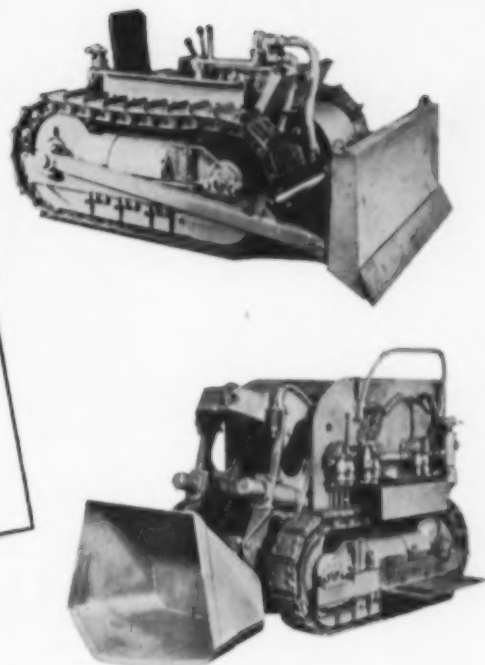
Jaw Crushers



Apron Feeders



**NOW! IN CRAWLER TYPE MACHINES  
FOR TRACKLESS WORK, THE SAME  
HEAVY RUGGED CONSTRUCTION AND  
DEPENDABILITY THAT THE INDUSTRY  
HAS HAD IN EIMCO WHEEL TYPE  
MACHINES.**



Fast, sharp maneuvers, regulated by fingertip control make the EIMCO 630 EXCAVATOR a production giant and an operator's delight.

With the power at his fingertips to move one track into forward motion while the other is in reverse motion, an operator can make the 630 veritably "walk" around a muck pile—working from any angle without backing to make a new approach.

Eimco 630 agility permits operators to quickly master movement of the machine to a point that lost motion is eliminated between excavating and discharge stages.

While the 630 is moving between points of excavation and dumping, the bucket progressively elevates in an arc. Through proper timing, arrival of the 630 and bucket discharge become simultaneous operations. And the large half-yard bucket provides greater tonnage at every discharge.

These three pluses—extra maneuverability, operational ease and larger bucket capacity added in terms of economic value to you mean **MORE TONNAGE IN LESS TIME.**



## **THE EIMCO CORPORATION**

Salt Lake City, Utah—U.S.A.

• Export Offices: Eimco Bldg., 52 South St., New York City

New York, N. Y. Chicago, Ill. San Francisco, Calif. El Paso, Tex. Birmingham, Ala. Duluth, Minn. Kellogg, Ida. Baltimore, Md. Pittsburgh, Pa. Seattle, Wash. Pasadena, Calif. Houston, Texas Vancouver, B. C. London, England Gateshead, England Paris, France Milan, Italy Johannesburg, South Africa

B-215

## On the Mesabi Iron Range



### EXTRA-TOUGH going calls for extra-tough AMSCO® DIPPERS...with Renewable Lip

On the Iron Range and in the Copper Mines, demands on dippers are really tough. And that's where Amsco Manganese Steel Dippers have proved they can "take it"...in years of rough use.

Amsco *Renewable Lip* Dippers are particular favorites here. For when the lip eventually wears out, this easily changed unit cuts "repair-time" to *one-tenth* that required for change-over of conventional designs.

The lip sides overlap and fit snugly into sockets in the back casting. Lugs on lip fit into slots in front

casting and are secured by forged, split keys. Sturdy U-bolts fasten lip to back casting, pulling it tightly to dipper when double nuts are screwed down. The result is one-piece rigidity and strength, free of play in any direction.

*You save two ways:* first, through the extra-long service life of Amsco Manganese Steel Dippers; second, through quick and easy replacement of the Renewable Lip.

See your shovel manufacturer for full information on Amsco Dippers, or write us direct.

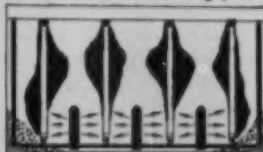


# AMSCO

American Manganese Steel Division • Chicago Heights, Ill.  
OTHER PLANTS IN: DENVER, LOS ANGELES, NEW CASTLE, DELAWARE, OAKLAND, ST. LOUIS, JOLIETTE, QUEBEC



Function of "impeller" design is agitation thru stirring. Results: Cake scour and uneven formation; vacuum less at thin sections near the periphery of disc. (Other methods included pipes for air and steam bubbling.)



This "rake oscillating agitation" design (from drum filters) is equipped with upright pieces of various shapes to increase agitation. The result: Cake scour and uneven formations due to direction of thrust.



The Eimco Agidisc method now used provides agitation straight-up between the discs, giving the many advantages listed in text at right.

## EIMCO AGIDISC FILTERS HAVE EXCLUSIVE ADVANTAGES

Eimco Hy-Flow Agidisc Filters give you these important advantages:

- 1) Even cake distribution without segregation.
- 2) Uniform thickness and dryness.
- 3) Higher tonnage capacity per square foot of filter area.
- 4) Drier cake.
- 5) Clean discharge.
- 6) Longer media life.
- 7) Lower maintenance costs.

After Eimco pioneered the agidisc filter, other manufacturers tried to match its performance by adding attachments to their existing filters.

Sketches at left readily show disadvantages of makeshift agitation.

The Eimco Agidisc is NOT a "patched up" version of other filter designs with doubtful operating merits. It is an integral unit. Scientific planning went into its distinctive design. Advantages were test-proven before it was marketed.

Confirmation that these filters are producing the advantages for which they were designed, is being received every day from Eimco Agidisc users.

**THE EIMCO CORPORATION**  
Salt Lake City, Utah—U.S.A. • Export Offices: Eimco Bldg., 52 South St., New York City

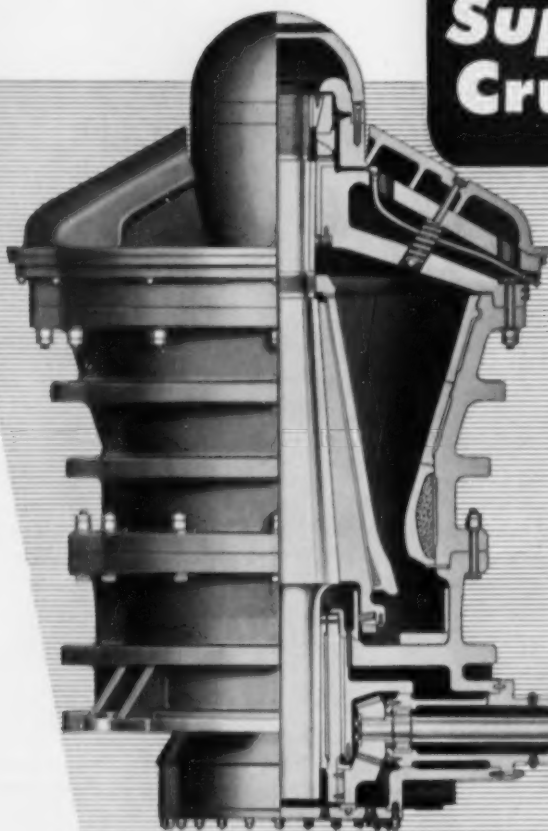
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3-517

Only one crusher gives you  
**Complete  
 Adaptability**  
 for a  
**BALANCED  
 CIRCUIT**

**Superior  
 Crusher**



• With a *Superior* gyratory crusher pacing production, your entire circuit remains in balance. Subsequent equipment—crushers, screens, grinding mills—need not be readjusted to varied product sizes and capacities. The many variable factors provided by the *Superior* crusher permit obtaining the kind of production flow demanded by your other equipment. For example, changing eccentric throws, crusher speed or shape of crushing chamber varies capacity and product size. The *bottom discharge* permits utilizing the concrete foundation as a surge bin to control flow of material through your plant.

*Hydroset* control is another factor in maintaining a balanced circuit. Retaining the initial crusher setting by compensating for wear is a one-man, one-minute operation when a *Superior* gyratory crusher is so equipped. Emergency unloading is made easier with just the flick of a switch.

A-4934

For complete information, see your A-C representative, or write Allis-Chalmers, Industrial Equipment Division, Milwaukee 1, Wis., for Bulletin 07B7870.

Superior and Hydroset are Allis-Chalmers trademarks.

**ALLIS-CHALMERS**



Hammermills



Vibrating Screens



Jaw Crushers



Gyratory Crushers



Grinding Mills



Kilns, Coolers, Dryers



# Manufacturers News

News  
Equipment  
Catalogs

• FILL OUT THE CARD FOR MORE INFORMATION •

## High Screen-Motor Mount

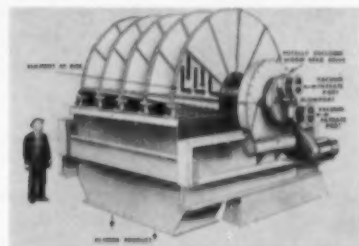
A new motor drive mount from Deister Concentrator Co. will save considerable space when a large number of Model E Leahy Heavy-Duty vibrating screens are employed close together. The mount is high and permits swinging the motor inward from its usual position beyond the side edge of the screen frame. **Circle No. 1.**

## Gamma-Ray Mill Control

Use of Isotope Products Density Gammagage for slurry density control in ore milling plants is claimed to result in a more uniform product, more efficient separation, and a minimum of recycling. Instrument utilizes gamma radiation to combine high sensitivity with non-contacting operation in control of ore concentration from raw ore feed to classifier overflow. **Circle No. 2.**

## Disc Filter

Denver Eqpt. Co. has a new 9-ft diam disc filter with 105 sq ft of filter area per disc. Patented filter segment design provides gravity drainage prior to discharge and results in drier filter cake. Twelve



segments per disc instead of the usual ten give the unit greater filter capacity because more complete segments are under vacuum in each revolution. **Circle No. 3.**

## Uranium Logging Cable



Waterproof cable of high tensile strength, low capacitance, and small diameter for use in uranium logging is offered by Belden Mfg. Co. Cable has a breaking strength of 250 lb and is furnished in continuous lengths up to 6000 ft. **Circle No. 4.**

## Wagon Drill

Designed for vertical or horizontal drilling in hard formations, a new wagon drill by Le Roi Div. of Westinghouse Air Brake Co. features a feed shell behind the center line of large wheel axles to provide stability. A welded tubular U-bar keeps



weight down. The entire unit, including feed shell and D14DR 4-in. drifter, weighs 1500 lb. Chain take-up adjustment results in smooth feeding, and a 2-gal capacity line oiler requires filling but once a day. **Circle No. 5.**

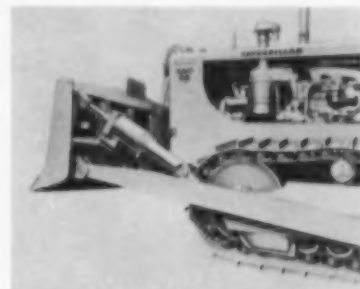
## Precision Level

Accuracy of plus or minus 0.01 in. in one mile of single leveling is claimed for the Wild N-3 Precision level by Wild Heerbrugg Instruments Inc. when used with the Wild Invar leveling staff. Coated lens telescope is internally focused and has a magnification of 42X. Bubble image is observed through 2X magnification to reduce eye fatigue. Three models are available and all include tilting screw, coincidence level, and built-in optical micrometer. **Circle No. 6.**



## Hydraulic Bulldozing

Bulldozing operations requiring frequent tilting of the blade will be speeded by the use of a new hydraulically actuated attachment by Caterpillar Tractor Co. for D8 and D9 Tractors. A large hydraulic cylinder replaces the left blade brace, and, by front or rear-mounted controls, the operator may raise the blade approximately two ft above ground while remaining seated. The right-hand brace is left in a neutral position. **Circle No. 7.**



## Nitrate Explosive

A new type of stripping and quarrying explosive said to combine the power and efficiency of fixed high explosives with the economy of low-order blasting agents has been announced by Atlas Powder Co. Called Amocore, the explosive consists of a basic cartridge charge of Amocol, an Atlas ammonium nitrate blasting agent, with a continuous gelatin initiator core. More complete detonation is said to result and intermediate booster charges are not needed. **Circle No. 8.**

## Underground Skid-Shovel

International Harvester Co. has introduced a new TD-9 crawler tractor Skid-Shovel equipped for underground mining operations. The 71-hp diesel crawler features an exhaust



gas scrubber and cooler, and an exhaust gas diffuser. It is designed to meet new USBM exhaust gas composition standards for non-coal operations. Standard attachments may be used and dimensions of the regular model are retained. **Circle No. 9.**

# CAT\* Motor Graders—now more than ever PROFIT MAKERS FOR YOUR MINE



This Caterpillar No. 12 Motor Grader works two shifts a day, six days a week the year around for the Tecumseh Coal Corp. of Boonville, Ind. Around-the-calendar Caterpillar dependability is traditional in mining work, where these versatile yellow motor graders find wide application in haul road construction and maintenance, snow removal and cleanup.

There are three Caterpillar Motor Grader models: the heavy-duty No. 12 with exclusive oil clutch, the No. 112, and the compact No. 212. Any one of them can reduce wear-and-tear on hauling equipment and step up cycle times with fast, smooth haul roads in *your* mine.

In the long run, Caterpillar Motor Graders cost *less* than other makes. Their economical, four-cycle diesel engines deliver full and foul-free power on inexpensive, non-premium furnace oil. Rugged construction and Caterpillar craftsmanship keep them on the job and out of the shop, and give them high resale value.

All Caterpillar Motor Graders are now available

with tubeless tires at no extra cost. Tubeless tires save the cost of tubes and flaps, eliminate 80% of tire down time, and deliver longer casing life and more recaps because they run 10 to 15 degrees cooler.

Caterpillar Motor Graders are built—not merely assembled—by a single manufacturer. Engine power, blade capacity and working speed are carefully matched for maximum efficiency and long work life. All parts and service are available from one dependable source: your Caterpillar Dealer. Ask him to demonstrate the excellent visibility, quick-acting, positive controls and balanced traction that will make a Caterpillar Motor Grader the fast-working favorite of operators in *your* mine.

Caterpillar Tractor Co., Peoria, Illinois, U.S.A.

## CATERPILLAR\*

\*Caterpillar and Cat are Registered Trademarks of Caterpillar Tractor Co.

**99% OF ALL CAT  
MOTOR GRADERS EVER  
BUILT ARE STILL IN USE**

**(21) TRAVELING PAN FILTER:** *Dorr-Oliver Inc.* has a leaflet on a vacuum filter designed specifically for handling strong phosphoric acid. A horizontal endless belt type, the filter consists of a series of individual filter pans mounted on an endless rubber belt driven by sprockets. Advantages claimed are flexible capacity, gravity feed, and sharp filtrate separation.

**(22) TESTING APPARATUS:** A new 128-page catalog from *Soiltest Inc.* contains descriptions and illustrations of over 1350 items of apparatus for engineering tests of soils, concrete, asphalt, and construction materials. Included are suggested laboratory layouts with equipment lists and excerpts from ASTM specifications.

**(23) CAUSTIC SODA:** *Dow Chemical Co.* offers a handbook on caustic soda that presents in detail chemical and physical properties, forms and grades, methods of handling, methods of analysis, technical data, economics.

**(24) DRILL BITS:** *Le Roi-Cleveland* one-use drill bits, their construction, specifications, and the preparation of drill rod shanks are given in 6-page Bulletin RD-29 from *Le Roi Div.* of *Westinghouse Air Brake Co.*

**(25) CRAWLER TRACK:** *Kensington Steel Co.* offers manganese steel crawler tracks said to have long service life. Featured is the anti-shear lug that fits snugly around the tie-bar on the rail link and is designed to eliminate end play and elongated bolt holes.

**(26) ROOF VENTILATOR:** *Butterfly damper* blades open automatically when a new Hi-velocity industrial roof ventilator by *Chicago Blower Corp.* is set into operation. Weather-tight in use or not, the unit is offered in blade diameters from 24 to 60 in. and exhaust capacities range from 6640 to 53,700 cfm. Damper head is of smooth galvanized steel.

## Free Literature

**(27) PERCUSSION BITS:** "Long body" bottoming type percussion bits and carbide blanks for bottoming drive rods are featured in an 8-page catalog by *Vascoloy-Ramet Corp.* Long body design is said to provide faster penetration, longer thread life, more clearance, and less chance of ring-off than shoulder type bits because the impact load is carried a shorter distance and is delivered to the bottom of the bit on the full cross section of the steel. Also described are bits and blanks for seven types of shoulder drive rods and 11 sizes for push-on rods.

**(28) COMPRESSOR TROUBLES:** Locating and correcting common air-cooled and water-cooled compressor troubles is simplified by a



new folder released by *Worthington Corp.* Each problem is separately treated with a list of probable reasons for poor performance in an ailing unit.

**(29) CAT 112 GRADER:** *Caterpillar Tractor Co.* has an illustrated booklet on the No. 112 motor grader. The 75-hp machine weighs 20,530 lb and standard equipment includes a 12-ft blade. Work capacity and performance are comparable to the No. 12 at a slightly lower speed.

**(30) COM-BIN FEEDERS:** *Pulva Corp.* has a new condensed catalog No. 5607 that describes a full line of equipment for storing and feeding mastic, plastic, sticky materials or dry solids. Com-Bin feeders will meter out material from pounds per minute to 100 tph and more.

**(31) GRINDING MILL:** *Patterson Foundry & Machine Co.* announces an improved ball and pebble mill with greater operator convenience and high efficiency at lower cost. Mill, designated Futura, features large jacket area and high water velocity for rapid heat transfer. Safety guardrail is counterbalanced for easy operation and interconnected with motor circuit. Capacities range from 455 to 1639 gal per batch.

**(32) WOUND ROTOR MOTORS:** Construction features of *Allis-Chalmers* wound rotor motors are detailed in a new bulletin. Motors are designed for use wherever high starting torque with low starting current is needed, power supply is limited, intermediate speeds are required, smooth acceleration is wanted, or where high inertia loads must be accelerated.

**(33) GLASS FIBER MASKS:** *Mine Safety Appliances Co.* has the "S" line of welding helmets and equipment. Strong and lightweight, the helmets are highly resistant to heat, moisture, and rot. Bulletin 0303-4 gives information on these protectors and on the M-S-A Nitrometer Mask for face protection from splashing chemicals. It provides a large aperture visor of clear plastic which may be easily replaced when needed.



## MAIL THIS CARD

for more information on items described in *Manufacturers News* and for bulletins and catalogs listed in the Free Literature section.



10

Mining Engineering

29 West 39th St.

New York 18, N. Y.

Not good after Jan. 15, 1957—if mailed in U. S. or Canada

Please send { More Information ☐ Price Data ☐ Free Literature ☐ } on items circled.

Name \_\_\_\_\_ Title \_\_\_\_\_

Company \_\_\_\_\_

Street \_\_\_\_\_

City and Zone \_\_\_\_\_ State \_\_\_\_\_

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
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41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64						

Students should write direct to manufacturer.



(34) **TRACTOR PARTS:** Folder from AMSCO Div. of American Brake Shoe Co. illustrates and points out advantages of manganese steel in track shoes, scraper blades, end bits, sprocket and idler rims, and grouser bars. It suggests the economical use of these replacement parts for tractors in quarries, mines, and slag-moving operations—or wherever heavy impact and abrasion are major wear problems.

(35) **CFIC CATALOG:** An indexed and fully illustrated 70-page catalog of principal products is available from the Colorado Fuel & Iron Corp. Listing classifications include heavy and special steel items, rails and accessories, wire and wire products, Wickwire rope, overhead conveying equipment, industrial screens and wire fabrics, hardware products, formed wires, processing belts.

(36) **RARE EARTHS:** The industrial future of the rare earths is still uncertain, but interest in these chemical cousins runs high. St. Eloi Corp. offers a brochure containing information on their properties that also includes current prices of available oxides.

(37) **FORGINGS:** Design, properties, and applications of brass, bronze, and aluminum hot-pressed forgings are treated in a 32-page booklet by Titan Metal Mfg. Co. Included is detailed information on available alloys and their properties, a commercial dimensional tolerance table, a list of forging terms. Factors of strength, core size, flash line, projections, staggered lines, fillets, and lettering in specifications and production are also included.

(38) **GREASE—HOT & COLD:** The influence of temperature on petroleum lubricating grease is the subject of Engineering Bulletin T-62 from The Brooks Oil Co. Discussed are the effects of temperature on consistency, apparent viscosity, adhesive and cohesive properties, and flow characteristics.

(39) **BIN LEVEL INDICATOR:** A rotating-paddle-type bin level indicator for use in hazardous atmospheres is announced by the Bin-Dicator Co. It is designed to indicate or control the level of bulk materials that will flow and is suited for application on bins under pressure or vacuum.

(40) **MOTOR GRADER OPERATION:** Caterpillar Tractor Co. has a 32-page manual with illustrations on the use of motor grader controls, basic blade positions and applications. Intended as a review handbook for experienced men and to help new operators, Form DE628 is pocket-size.

(41) **FURNACE CONTROLS:** Condensed bulletin and price list B43-1 from Minneapolis-Honeywell Regulator Co. on furnace and oven controls introduces the ElectroniK line of strip chart, circular chart, and circular scale instruments. Flame safeguard devices, motorized valves, and diaphragm control valves are also listed.

(42) **JERSEY SPECIAL:** "Services Available to Industry in New Jersey" is the title of a 100-page handbook available from Rutgers Univ. for distribution throughout the state. Directory is designed to point the way to the solution of various industrial problems, particularly those encountered by small firms. An alphabetical index provides a convenient method of locating specific organizations, and a subject index simplifies finding the source of a particular service or product.

(43) **TRACTOR SHOVEL:** An 8-page brochure on the HD-8G tractor shovel is offered by Allis-Chalmers. A two-position bucket on the 19,600-lb machine has 1½-cu yd capacity. Unit construction allows major units to be serviced without removing adjacent assemblies. Booklet includes specifications of interchangeable matched attachments.

(44) **ANALYTICAL BALANCE:** Data sheet from LaPine & Co. describes the Reyers-Progress balance which is accurate to 1/100,000 of capacity. Balance includes a knob-controlled 0-1000 mg fraction loader.

(45) **CONCRETE GUNNING:** Concrete may be pneumatically applied with the Model PM-2 Blastcrete gun from Blastcrete Eqpt. Co. Tensile strength of gunned concrete is higher than poured concrete and the use of forms can often be eliminated. Insulating, light weight refractory, heat and acid resisting material premixed or otherwise may also be successfully applied.

(46) **FIRST AID CABINET:** A new first aid wall-mounting cabinet with rounded corners and flush chrome hardware is available from the General Scientific Eqpt. Co. Finished in white enamel, the cabinet is 20 in. high, 24 in. wide, and 11 in. deep.

(47) **LOOSE DIAMONDS:** A brief discussion of industrial diamond sizes, uses, and terminology is given in an illustrated folder available from Diamond Tool Research Co. Inc.

(48) **TAR COATING:** Tapecoat SP is a coal tar coating in tape form for simple spiral wrapping of pipes. Tar-saturated, close-woven fabric serves as both bond and protection and is applied as it is lightly heated with a torch. Clean to handle, its liner is disposed of in the heating process. Rolled tape is made in 2, 3, 4, and 6-in. widths by The Tapecoat Co.

(49) **BULK LOADING NOZZLE:** Rapid, even distribution of bulk materials in cars, vans, and bins is claimed for a swivel nozzle from Fuller Co. Nozzle consists of a bent aluminum tube fitted into the center of a standard or custom designed hatch cover. When fitted to the hatch with a rubber gasket the cover prevents escape of material, and the nozzle can direct the flow to all parts of the container.

(50) **X-RAY DIFFRACTION:** "X-Ray Diffraction for Research, Production Control . . . and Profit" is the title of a 4-page brochure released by the General Electric X-Ray Dept. Discussed are basic theory, definitions, analytical advantages and applications in subjects including mineralogy and metallurgy. Shown are typical patterns of methods of crystal study—Laue, rotating crystal, and powder.

(51) **CONVEYORS:** Barber-Greene Co. has a photo story on the use of their standardized conveyors in a plaster board and plaster plant. Versatility and cost-cutting are pointed up as advantages of their standardized components in Form 3547.

**FIRST CLASS**  
PERMIT No. 6433  
Sec. 34.9 P.L.&R.  
New York, N. Y.

### BUSINESS REPLY CARD

NO POSTAGE STAMP NECESSARY IF MAILED IN THE UNITED STATES

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29 WEST 39th STREET

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## Digs MORE

At Mohave Mining & Milling Co.'s sintering plant the powerful break-out action of the model HU "PAYLOADER" works the bucket into tough, heavy ore and tips it back 40° at ground level to get bigger loads, with less spillage.



## Carries MORE

The heaped load is cradled close to the machine for greater stability and can be carried at lower level. Exclusive load shock-absorber cushions the load during travel, smooths out the ride and permits faster movement with less spillage.



## Delivers MORE

Because the "PAYLOADER" gets MORE to begin with and carries MORE while traveling at higher speeds... with less spillage in both instances... the result—you deliver MORE. "PAYLOADER" design handles more yardage at lower cost.



## More Productive Capacity

Whether you want to move manganese ore like this, or larger-size ore and rock, "PAYLOADER" tractor-shovels are designed to get and hold bigger loads and deliver them faster.

"PAYLOADER" superiority on materials handling at mine, mill and smelter is the result of 34 years of pioneering and leadership in tractor-shovel manufacture. "PAYLOADER" preference in the mining industry also comes from the fact that "PAYLOADER" is a complete proven line—there's a size and type to best meet each need—PLUS the finest parts and service facilities at the nearby "PAYLOADER" distributor.



**PAYLOADER®**

THE FRANK G. HOUGH CO. LIBERTYVILLE, ILL.  
SUBSIDIARY—INTERNATIONAL HARVESTER COMPANY



**THE FRANK G. HOUGH CO.**  
916 Sunnyside Ave., Libertyville, Ill.

Send "PAYLOADER" information as follows:

- ☐ Front-wheel-drive — to 1 cu. yd.
- ☐ Rear-wheel-drive — to 1½ cu. yd.
- ☐ Four-wheel-drive — to 2¼ cu. yd.

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Title

Company

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State



**World's Largest Shovel** is the Mountaineer, built by Marion Power Shovel Co. for Hanna Coal Co. It is 16 stories high, and scoops up overburden in 90-ton bites. USS "T-1" steel

is specified for such major components as the bucket, dipper stick and crowd rack; to assure the strength, toughness and ruggedness that adds up to long service life.

## "T-1"...a super-tough nickel alloyed steel prevents breakage...slashes downtime

At 38°F below zero...or at 900°F above..."T-1" steel stays *super-tough!*

Downtime troubles *go out* when "T-1" steel *goes in* dipper sticks, shovel buckets, car bottoms, bulldozers and other mining equipment.

That happens because "T-1" steel is a constructional alloy steel combining exceptionally high levels of strength and toughness.

It stands up under heavy shock loads. Curbs breakage the year 'round.

### **Note its advantages:**

**90,000 psi minimum yield strength.**

**Readily weldable . . . needs no preheat nor stress relief.**

**Resists impact at sub-zero temperatures.**

**Four times as resistant as carbon steel to atmospheric corrosion.**

Use "T-1" steel for heavily stressed parts. Watch them stay on the job, earning profits. Why take chances with steel of lower yield strength and consequent risk of failure in service? Idle men and machines make it a costly proposition...so, put "T-1" steel to work now.

For details on USS "T-1" steel, write to United States Steel Corp., Pittsburgh 30, Pa.



**THE INTERNATIONAL NICKEL COMPANY, INC.**

67 Wall Street  
New York 5, N. Y.  
PRINTED  
U.S.A.

### **Zirconium Test Plant is Kennecott Project**

A new test plant for the electrolytic production of zirconium has been planned by Kennecott Copper Corp. with operation to begin late next year. License for manufacture was acquired from Horizons Titanium Corp. in an agreement that provides options for electrolytic production of other metals, including titanium, thorium, columbium, and tantalum.

### **Olin Revere to Produce Aluminum**

Olin Mathieson Chemical Corp. and Revere Copper & Brass Inc. have announced formation of a \$231 million firm, Olin Revere Metals Co., to produce primary aluminum in the Ohio River Valley. Production of 180,000 tons annually is expected.

### **Copper Merger Proposed in Canada**

Copper Cliff Consolidated Mining Corp. and New Royan Copper Mines Ltd. stockholders will vote on a proposed sale of these firms to their wholly-owned subsidiary, Copper Rand Chibougamau Mines Ltd. Merger, if approved, will be made through an exchange of shares.

### **Columbium—Canadian Discovery . . . New U. S. Plant**

Largest known single deposit of columbium has been reported discovered at Oka, Quebec, near Montreal . . . Fansteel Metallurgical Corp. has announced plans to build a \$6 million plant for the production of columbium and tantalum metal.

### **Beryllium Metal Facilities Planned in Pennsylvania**

Plans for construction of a \$4 million plant for the production of nuclear grade beryllium metal at Hazleton, Pa. are reported by Beryllium Corp. The new facilities will be designated the Nuclear div. of the firm.

### **Mining Products Lead Canadian Exports**

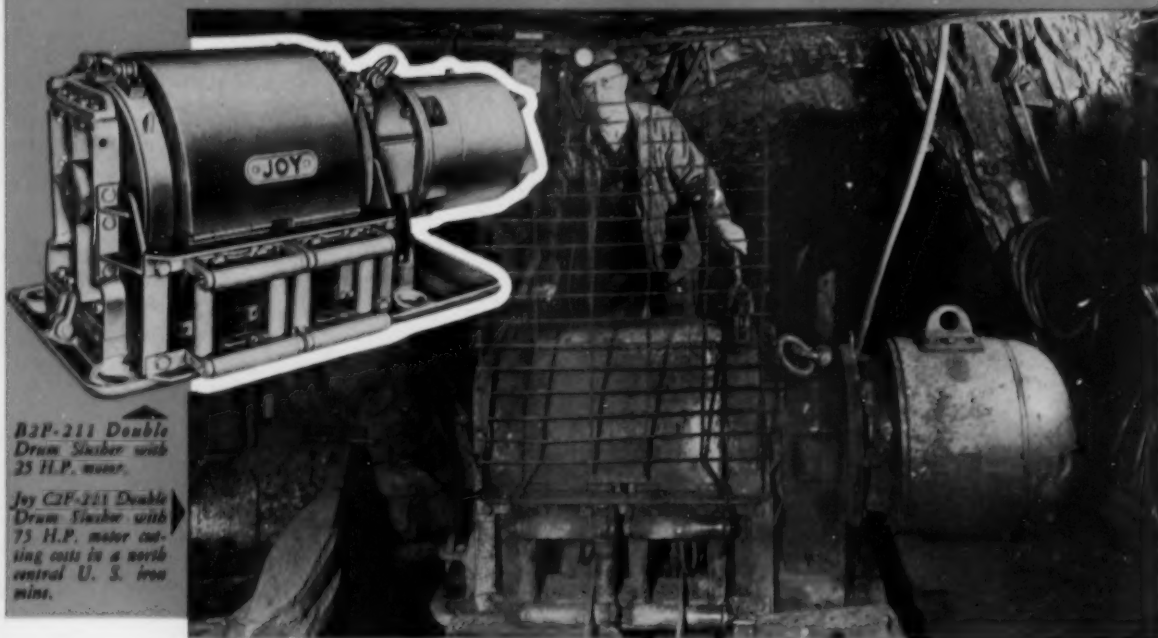
According to an estimate in *The Northern Miner*, Canada "exported or had available for export, over \$579 million worth of primary ores, metals and minerals in the first six months of 1956." Pulp and paper, the former export leader, totalled \$531 million in the same period. . . . A record production of nickel, 174,000 short tons, was reported for 1955.

### **Coal Slurry Pipeline Ready Soon**

Pittsburgh Consolidation Coal Co. reports laying of 110 miles of pipe in Ohio for the first commercial shipping of coal via pipeline. By early next year the line, with a capacity of 150 tph, will begin supplying coal to the Cleveland Electric Illuminating Co. A contract calls for delivery of 18 million tons over the next 15 years. Three pumping stations are still to be completed.

HAUL ORE AND ROCK AT LOWEST COST

# WITH JOY A-B-C Slushers



B3F-211 Double  
Drum Slusher with  
25 H.P. motor.

Joy C2F-211 Double  
Drum Slusher with  
75 H.P. motor cut-  
ting costs in a north  
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mine.

The A-B-C's of low cost scraping are not learned in school—you learn them in the field. Joy A-B-C slushers, A2F, B2F, and C2F, two and three drum, have demonstrated, in mine after mine, their ability to haul at rock bottom cost. It's not hard to learn why.

Joy A-B-C slushers operate at lower cost because clutches are bigger and wider for longer life—for longer intervals between adjustment and relining. Rugged construction with one-piece rigid base keeps all working parts in perfect alignment. Large drum diameters give longer rope life. A-B-C slushers reduce operator fatigue because their clutches are 100% self-energizing.

For simple, low-cost maintenance Joy A-B-C slushers have only one grease fitting per drum . . .

to service each drum's planetary gear train. Grease reservoirs adjacent to shielded type ball bearings provide lubrication as needed. Clutch bands and adjusting nuts are out in the open, easily accessible for adjustment and relining.

These are just some of the cost saving features built into the Joy A-B-C line. They are available with flange mounted electric or air motors from 10 to 75 H.P.

Why not find out more about the A-B-C's? Write to Joy Manufacturing Company, Oliver Building, Pittsburgh 22, Pa. In Canada: Joy Manufacturing Company (Canada) Limited, Galt, Ontario.

WGW-N-6244-121

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HOISTS and SLUSHERS, MINE FANS AND BLOWERS

# JOY

WORLD'S LARGEST MANUFACTURER OF  
UNDERGROUND MINING EQUIPMENT



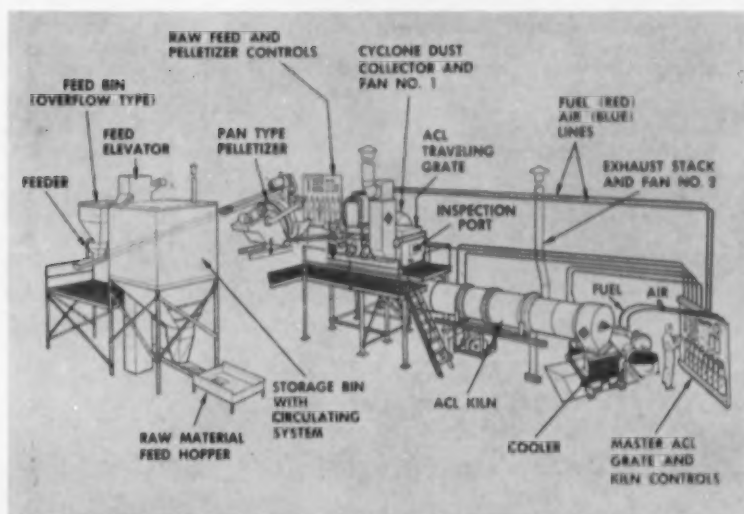
## ACL Cement Process Makes Use of Fly Ash

The same fly ash that pelts the face and offends the eyes when you pass a power generating station has been found usable as a substitute for shale in cement plant feed. The first unit of Marquette Cement Co.'s new Milwaukee plant will be supplied with approximately 50,000 tons of the material per year by an electric power company in Wisconsin. About 15 pct of Marquette's raw feed will be made up of fly ash to be used as a shale substitute.

Utilization of fly ash in cement production promises an important new outlet for large tonnages of the material. The problem of removing carbon from the ash can be solved, it was found, by preprocessing with commercially available gyratory screens.

Fly ash is also ideally suited for a new ACL cement manufacturing process which requires a pelletized feed. Raw materials are carefully blended to their proper proportions which are maintained in pellet form to assure uniformity of mix throughout the process and uniformity of the end product—cement clinker.

Even though fly ash is substituted for shale or clay, the fuel requirements are expected to remain low. Besides pelletizing of the feed, the ACL method requires a traveling grate for drying and partially burning the pellets, and a short kiln for final burning with an overall saving in space required.



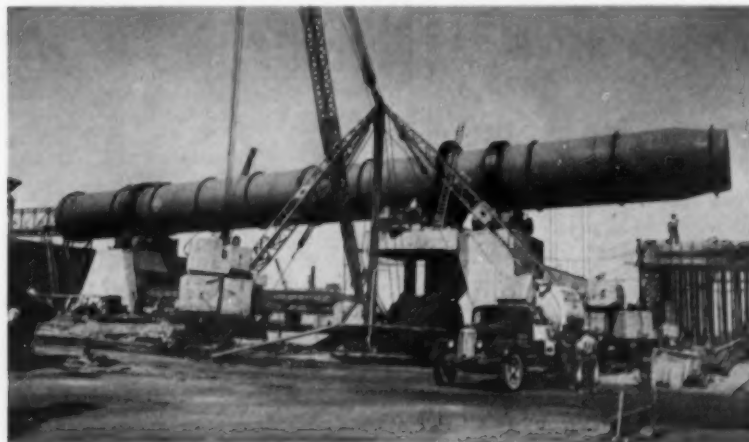
Overall view of ACL pilot plant traveling grate and kiln, having a production rate of about 300-400 lb per hr. The cement process is claimed to offer low dust loss and low fuel consumption. These facilities are located at the Allis-Chalmers Heat Hardening Laboratories, Carrollville, Wis.

Pelletizing the raw mix keeps from start to finish the original blend of the various components, preventing segregation of the finely ground raw materials. Pellet size is from  $\frac{1}{8}$  to  $\frac{3}{8}$  in.

Space requirements are reduced as much as 40 pct in some cases. This feature, coupled with the extremely low dust loss, makes possible the manufacture of cement in urban areas previously considered unusable for that purpose. Full-scale ACL kilns will range from 120 to 175 ft long, with 10½ to 13 ft inside diam. The traveling grate will add a maximum of about 85 ft to the length, still shorter than conven-



Note uniformity of the pellets here being discharged from pan type pelletizer onto belt which carries them to ACL traveling grate. Proportions of the blended mix cannot vary anywhere in the system after it is put into pellet form.



Rotating portion of ACL kiln for Marquette Cement Co., Milwaukee in process of erection. Unusually short section will be used in conjunction with a heat-recovering grate to be mounted to the extreme left of the kiln as shown here.

tional kilns which are 300 to 500 ft long.

The traveling grate replaces what is normally referred to as the feed end section of a conventional kiln. The grate enclosure is divided into two sections—the drying and pre-burning chambers. Pellets first enter the drying chamber where they are exposed to a downdraft at 500° to 600°F. Pellets are dried and exhausted to atmosphere at 200° to 250°F.

The pellets next enter the pre-burning chamber where they are exposed to a downdraft of hot kiln exit gases at 1700° to 1800°F. Here

the pellets are partially calcined (25 to 35 pct) and become hard before entering the feed end of the rotary kiln. This double pass of the gases through the pellet bed is expected to result in extremely low dust loss without additional dust collectors. Savings in space, in cost of dust collection, as well as potential fuel savings of up to 30 pct are the advantages claimed for this process which combines traveling grate and short kiln as opposed to a single long kiln.

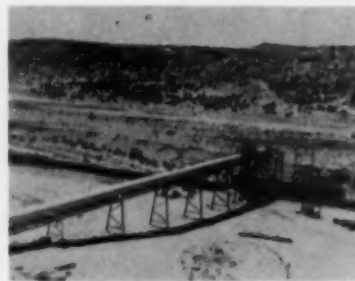
Wisconsin will have the first full-scale ACL system in the U. S., located near the heart of downtown Milwaukee.

## Big U-Ore Crusher

### Keeps Wind Loss Down

Set up at an open-pit uranium mine near Laguna, New Mexico, a large overhead eccentric jaw crusher is efficiently reducing uranium ore for The Anaconda Company prior to shipment from its Jackpile mine to a concentrating plant near Bluewater, N. M.

The ore is being hauled from open-pit mining operations by 22-ton end-dump hauling units, and blended as to grade at the crusher.



From crusher to waiting rail cars the uranium ore is protected from wind loss by a sheet metal cover over its conveyor system.

## FOR PROFITABLE SCREENING USE



5' x 12', Type F-600  
TY-ROCK SCREEN  
with Tubular Base.

## TYLER VIBRATING SCREENS AND TYLER WOVEN WIRE SCREENS

There is a Tyler Vibrating Screen for every sizing and dewatering job. Tyler Screens are noted for the huge tonnages handled with top efficiency and low cost per ton.

Tyler Woven Wire Screens are made in all meshes and metals in over 10,000 different specifications. Ton-Cap and Ty-Rod Screens with the long-slot openings provide the greatest capacity for a given discharge area.

## THE W. S. TYLER COMPANY

CLEVELAND 14, OHIO

Manufacturers of Woven Wire Screens and Screening Machinery

This is done to assure fairly uniform content as ore flows from mine to concentrating plant. Blending is done by loading ore, with varying degrees of enrichment, in various parts of the pit; then dumping these trucks in order according to a production-blending sheet made out each morning by production managers.

The 80-ton capacity feeder hopper with sloping steel sides terminates at the bottom with a feeder which moves the uranium ore across a sloping set of grizzly rails which pass all minus 8-in. material. Over-size chunks of ore slide off the grizzly rails into the jaw plates of the 42 x 48 Pioneer crusher, which is powered by a 200-hp diesel engine.

Uranium ore from below the grizzly deck and under the crusher passes over a 48-in. conveyor delivery belt, 425 ft long, to loading spouts which train the material down into railroad cars.

A feature of unusual interest is the protection of the crusher housing, the feeder trap area, and the 425-ft conveyor belt from prevailing winds which could blow fine uranium dust away in quantities which would be of economic concern. A fully enclosed rolled sheet half-round protective shed has been built over the conveyor delivery line, and construction is under way to enclose the jaw crusher and feeder trap areas completely. Also, as a concession to wind erosion, the railroad cars are not being filled to full capacity.

# New CAT\* No. 9 Ripper

## FOR THE

# Mighty D9!

First choice for push-loading, the D9 is now more versatile than ever. The new No. 9 Ripper lets the D9 rip tough or frozen material between loading cycles. Faster, easier scraper-loading cuts time and costs.



### TRACTOR-MOUNTED

The tractor-mounted No. 9 Ripper utilizes the weight of the D9 to force the teeth into hard material. No need for ballast or extra weights. The hydraulically operated ripper affords maximum maneuverability because it is tractor-mounted.

### "LIVE DRIVE" HYDRAULIC PUMP

New No. 50 Hydraulic Control has a constant power pump that supplies the capacity to raise or lower ripper teeth independently of flywheel clutch or torque converter.

### TWO RIPPING POSITIONS

Shanks may be pinned in either of two ripper positions which provide either maximum ground clearance when raised or maximum penetration (up to 28") when lowered.

### TRIPLE TEETH

Use one, two or three. Any or all of them can be swung up and pinned out of the way. Teeth pivot 10° to either side. This permits tractor steering and smoother ripping through rocks. Shanks are heat-treated alloy steel, with hardened alloy cast steel boots. Points are hardened cast steel, pin-attached for easy replacement.

### MANY OTHER IMPORTANT FEATURES!

Now the new No. 9 Ripper makes the "King of the Crawlers" an even more profitable and versatile machine. Mail the coupon for full details, or call your nearby Caterpillar Dealer. And remember, you can count on him for reliable service, and for parts you can trust.

Caterpillar Tractor Co., Peoria, Illinois, U. S. A.

## CATERPILLAR\*

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TRACTOR RIPPERS**

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## Bulk Mineral Storage by the SAUERMAN Method



Reclaiming Triple Superphosphate to Hopper

### How Sauerman Scraper Storage Reduces Costs

200,000 tons of triple superphosphate are produced each year in this new Florida plant. It is delivered by overhead conveyor to a 329' x 146' storage building of 35,000 ton capacity. The material is then stockpiled and reclaimed by a 2½ cu. yd. Sauerman Scraper at a rate of 150 tph.

Here's how a Sauerman Machine cuts costs:

One operator, located in a safe station overseeing the entire area, can recover practically 100% of all stockpiled material.

All highly machined parts, hoists and motors can be located outside of the building and protected from corrosion and dust.

When parts are replaced—sheaves, clutch or brake linings—the machine is restored to practically new condition, even though it may be twenty or more years old.

Only the Crescent scraper and cables contact the material. The scraper machine can be designed to operate the scraper on top of non-caving material. This allows the scraper to break down any high faces that may be standing.

Sauerman Storage Machines are built for hourly capacities of from 20 to 600 cu. yds. A partial list of producers and manufacturers using some type of Sauerman equipment includes:

Consumer Cooperative Assn.  
Crawford Chemical Co.  
Devion Chemical Co.  
Division of W. R. Grace & Co.  
Duval Sulphur & Potash Co.  
F. S. Royster Guano Co.

International Minerals & Chemical Corp.  
Lion Oil Co.  
Potash Company of America  
Tennessee Farmers Cooperative  
Virginia-Carolina Chemical Corp.  
Southern Agricultural Fertilizer Co.

For ways to reduce your material handling costs, write to Sauerman's experienced engineers. Request Catalog E, *Bulk Storage by Scraper*, plus Field Report 227, and other reports on the handling of your material by Sauerman Machines.



Overall View of Storage

## Sulfur Deposit To be Mined Offshore

An offshore sulfur mining operation will be undertaken by Freeport Sulphur Co. at a deposit discovered in the Gulf of Mexico by Humble Oil & Refining Co.

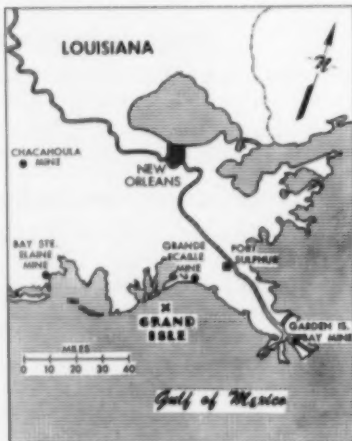
The deposit, located off Louisiana in 45 ft of water six miles from land, represents a "major new source of sulfur," according to a joint announcement. A contract calls for Freeport to design, install, and operate a mining plant to produce sulfur by the Frasch hot water process. Construction is required to begin by the latter part of 1958 and is expected to take two years to complete.

The sulfur was found, in the course of oil exploration, approximately 1700 ft below the floor of the Gulf in the caprock of a salt dome.

The water-heating plant and other installations will be built on a tall structure, out of reach of storm waves.

In the absence of storage space, insulated barges will shuttle the sulfur in molten form to Port Sulphur, a 25-mile distant storage and shipping point. On the return trip, the barges will haul fresh water necessary for boiler makeup and auxiliary services. The Gulf itself, however, will supply the millions of gallons of water required daily for injection into the wells at high temperature.

Freeport has developed and successfully operated other sulfur mines in the coastal marshes. Two of the mining plants were erected on 75 to 95-ft piling, and a third was built on a barge, floated to the site, and sunk in place.



Sulfur will be mined at the Grand Isle deposit located off Louisiana in 45 ft of water six miles from shore. Freeport now mines sulfur from four other coastal deposits: Grand Ecuille, Garden Island Bay, and Bay Ste. Elaine, all in delta marshland, and Chacahoula, in the midst of a cypress swamp.

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BELLWOOD, ILL.

Crescent Scrapers • Slackline and Tautline Cableways • Durolite Blocks



# new JR-38B JACKDRILL

has **7** improved features

for **EASIER OPERATION & LESS MAINTENANCE**



1. **NEW STEEL CENTRALIZER** with all working parts enclosed within the fronthead and protected against dust and dirt. Maintenance virtually eliminated.
2. **NEW ONE-PIECE CHUCK** with easily renewable bushing — stronger, easier to maintain. Bushing recessed to take drill steel collar — keeps water away from the operator. Constant air bleed around chuck collar keeps cuttings out of the drill — longer, trouble-free operation and less maintenance.
3. **NEW ROLL-TYPE FEED CONTROL HANDLE** gives operator positive, more convenient control of feed-leg pressure — smoothly variable from zero to full supply pressure — can be reversed for right or left hand operation. Push-button valve in end of control knob permits instant relief of feed pressure.
4. **NEW EASY WATER TUBE REPLACEMENT** water tube can be replaced without disassembling the Jackdrill by removing backhead plug.
5. **NEW STOPER CONVERSION** permits Jackdrill backhead to be replaced with a conventional Stopehamer backhead. Simplifies parts inventory and maintenance wherever Jackdrills and Stopehamers are used on the same job.
6. **NEW EASIER DISMANTLING** of feed leg — saves maintenance down-time.
7. **NEW TELESCOPIC FEED LEG** is 10 pounds lighter in weight than previous design — makes Jackdrill easier to handle and transport.

**W**ITH these new features, the I-R Universal Jackdrill is now better than ever — setting new standards of ease and economy — *it will stay underground*. It's not just a Jackhamer-Jackleg combination, but a completely integrated Jackleg Drill, with single air hose connection and all operating controls centralized on the drill backhead. Ask your Ingersoll-Rand representative for complete information on the time-saving, cost-saving features of the new and improved JR-38B Jackdrill.

5-409

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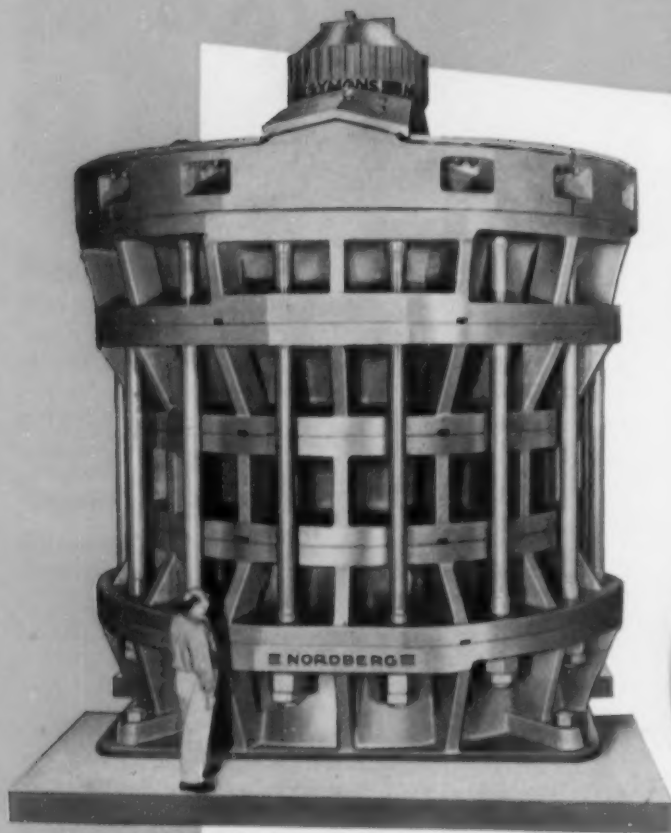


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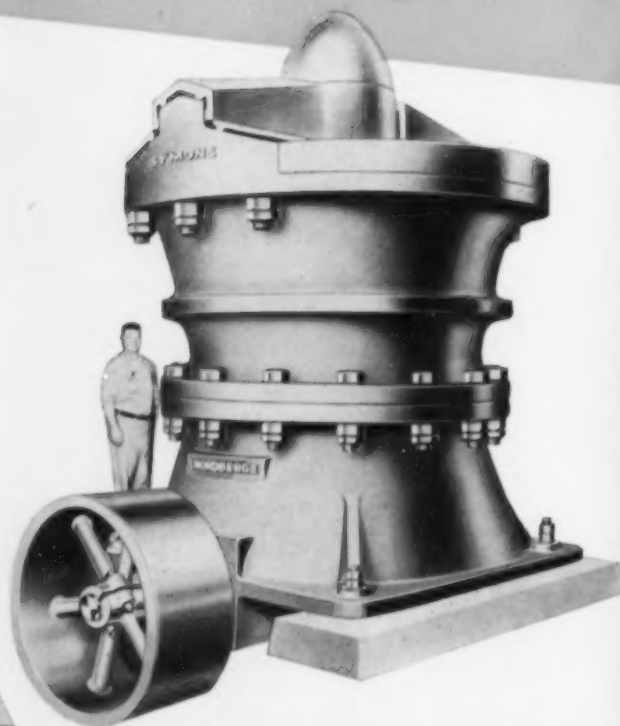
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SYMONS 30" GYRATORY CRUSHER



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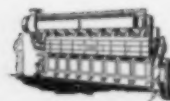
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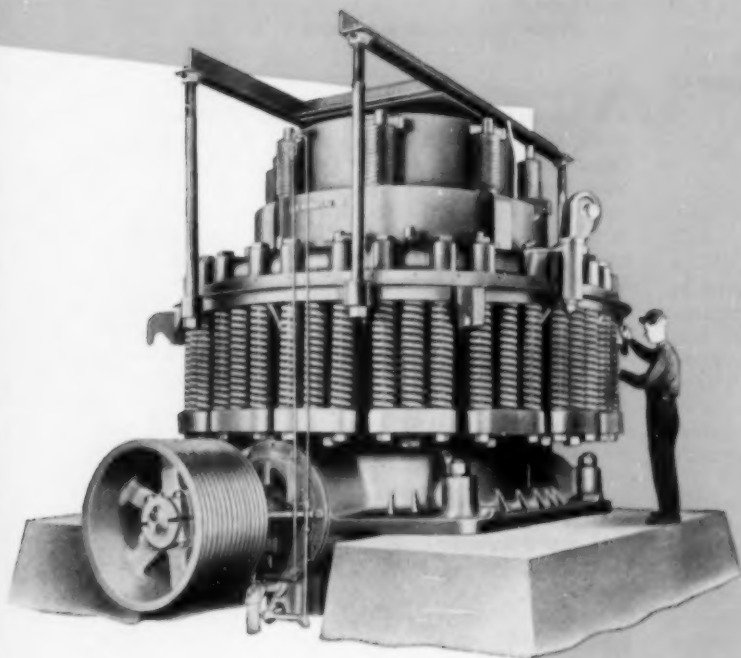


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SPARK-IGNITION GAS ENGINES

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... greater productivity  
through more efficient crushing

Complete range of sizes from  
6 to over 3500 tons per hour



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For secondary and finer reductions, Symons Cone Crushers, in both Standard and Short Head types, are available in sizes ranging from 22" to 7'—in capacities from 6 to 900 or more tons per hour.

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**A** PROGRAM for continuing and extending co-operation with friendly nations in uranium exploration has been approved by the AEC. Through a recent announcement the U. S. offers assistance to other nations in their uranium exploration programs through access to information on geology and exploration techniques.

Geologists and technicians in interested countries will be encouraged to visit the U. S. to study deposits and AEC laboratory and exploration projects, while AEC personnel may make brief visits to other nations to discuss techniques and to make brief preliminary investigations.

It is believed that the rapid progress of civilian atomic application, particularly for nuclear power projects, will stimulate development of resources in many nations to meet their own civilian needs. The AEC indicates that it is likely that the activities permitted in the announcement will develop into co-operative foreign exploration projects similar to those approved by the Commission over the past few years. Since 1951, projects have been undertaken or are underway in: Australia, Bolivia, Peru, Venezuela, Colombia, the Philippines, and Turkey. Brief appraisals have been made in a number of other countries.



**A**S SOON as a special Engineering-Secretarial course was initiated last year at Business Training College, Pittsburgh, Dean Phyllis Davis was deluged with calls from the engineering profession for graduates. However anxious engineers will have to wait for the strains of "Pomp and Circumstance." First graduates of the unique professional classes to provide scientific background for administrative assistants will not be available until next year.

It looks as if the men and women completing the two-year course will be snapped up by individual engineers, engineering firms, and the professional associations throughout the country.

The college aims to give young men and women training to enable them to assist busy engineers who do not have time to be concerned with details that can be handled by someone who understands the language of the profession. The Engineering-Secretarial course is planned to give students a scientific background in addition to the secretarial skills. Background subjects include chemistry, physics, advanced mathematics, and the terminology of the various fields of engineering. In addition there is an intensive course in filing and blueprint reading.

The college reports that it is most important to select students who have not only an interest in the field, but who have the innate ability, aptitudes, and intellectual curiosity necessary for scientific professional training.

Address of the school is 550 Grant St., Pittsburgh 19, Pa. (Line forms to the right, please.)

**M**AINE is swinging into action on the geological front, particularly with emphasis on collecting and making available data on its granite resources. First step in this program is collection of data from 19th century granite operations, hitherto largely scattered in scientific journals and individual company records. Reports will give location of deposits, ownership, commercial nature, development, and reference to published information in a series of mimeographed sheets.

Enthusiasts report that the Pine Tree State has great mineral potential—but one that is largely uncharted. Geological mapping has lagged behind that in other New England states, with only 2.5 pct of its area covered by detailed geological maps of modern standards. According to Maine the other five New England states can report from 6 to 53 pct mapped the modern way. The state now employs a full-time geologist in the Dept. of Industry and Commerce.



**A**N interesting recognition of the versatility and broad interests of engineers and scientists is being made by the scheduling of a photographic salon at the National Chemical Exposition, Cleveland, November 27 to 30. The photographic show is an innovation for this type of technical exhibit, for it solicits not only technical work, but pictorial prints and slides that technical and scientific workers enjoy taking in their leisure moments. Among the names of the six judges, all prominent technically, we note active AIME member Walter Dean, works chief metallurgist of ALCOA, Cleveland.



**O**NE hundred and thirty-two years ago an English bricklayer, Joseph Aspdin, invented the basis for the biggest heavy chemical industry—portland cement. By last year the industry's output had risen to 300 million bbl, or about 2 bbl per person in the U. S., and output shows no sign of a let up. Forecasts are for manufacturing capacity of about 350 million bbl by year-end, 400 million bbl capacity by 1957-58, and still higher figures by completion of programs projected to 1960.

Last year the industry mined and quarried about 90 million tons of raw materials, or nearly as much as the tonnage of iron ore mined in the U. S. making portland cement also one of the nation's big mining ventures. Still in midst of intense post war expansion the industry apparently looks to the future with a bullish eye, especially in the light of some of the proposed Federal highway construction programs. Having tripled production between 1945 and 1955 it is not hard to believe it will have quadrupled or more by 1960.



A RECENT press release reports a 3655-mile airborne magnetometer profile, from New Delhi, India, to Manila, P. I. The record was obtained by Spartan Air Services Ltd. and Canadian Aero Service Ltd., during a flight by a Dakota to a new operations base. This is the fourth of these profiles we have noted, and although it is probably years too early to assess their value, the accumulation of data on hemispheric scale is doubtless the forerunner of another step forward in geological knowledge.

This profile was taken on a course from New Delhi to Calcutta, to Bangkok, to Labuan, to Manila at an altitude of about 1000 ft. A continuous record was obtained with a Gulf magnetometer, except for the Bangkok area where monsoons interrupted things. W. B. Agocs of Canadian Aero Service will make a complete analysis of the record to tie it into known geological data of the area.

Previous flight lines have been from Tunis to Lisbon, and from Johannesburg to New Delhi. A report on a profile taken over the northwestern U. S. that was first presented at an AIME annual meeting will be published in Mining Transactions within the next few months.



THE nation's ability to wolf down aluminum at an ever-increasing rate seems destined to outmatch industry's ability to construct new capacity for some time to come. Prior to World War II, production of less than 200,000 tons was undertaken by a solitary company, Aluminum Co. of America. Both World War II and the Korean War greatly stimulated capacity expansion, however, and today aluminum is no longer the mere pot metal of former years. Commercial air travel has filled the skies with planes built of aluminum; sleek aluminum-clad trains carry thousands of passengers; aluminum occupies an ever-growing role in the millions of automobiles on the country's highways; some 200 office and apartment buildings now have aluminum cladding; and countless scores of interiors feature designs making use of aluminum. Electrical uses are becoming more important, and the metal is finding an ever widening field in packaging.

To meet these demands, Reynolds Metals Co. entered the aluminum field in 1941, Kaiser Aluminum & Chemical Corp. followed in 1946, and Anaconda Aluminum Co. several years later. As of July 1, 1956, U. S. capacity to produce primary aluminum ingots was estimated at 1,737,000 tons.

Aluminum Co. of America, Kaiser, and Reynolds are each erecting an aluminum reduction plant with capacity in excess of 100,000 tons. Added to this are the plans of Olin-Mathieson Chemical Corp. and Revere Copper & Brass Co. to set up a new firm for the purpose of erecting a 180,000 ton aluminum plant at Clarington, Ohio. Harvey Machine Co. states that it will break ground for a new plant at

The Dalles, Ore. with an annual capacity of 54,000 tons of aluminum ingot.

These vast expansion plans represent an increase of more than 40 pct of present capacity and will bring total U. S. primary aluminum capacity to 2,485,000 tons by 1958.

Five out of every seven tons of bauxite used by U. S. plants is imported, and the majority of this originates in the great bauxite mines of Jamaica, Surinam, British Guiana, and Haiti or the area of the Caribbean Sea and northern South America. The U. S. is no longer drawing upon bauxite from more distant points.

Present expansion plans for aluminum may have to be further extended as the market continues to grow. Mr. Henry J. Kaiser, the chairman of the board and president of Kaiser Aluminum & Chemical Corp. said, "Aluminum usage in the United States continues showing the rapid growth that has characterized the industry for the past several years. It is our conviction, based on our extensive surveys, that this trend will continue and that by 1965 the United States will be using aluminum at twice the present rate—more than four million tons of aluminum a year."



SEVERAL major organizations are expanding research facilities to increase their knowledge of nuclear radiation, some with positive goals in mind. Applied by various methods, irradiation has been found applicable to improving plastics; preserving foods and drugs; processing chemicals, rubber, and oil.

One oil research quest is aimed toward a cold cracking method by which radiation might produce the changes in petroleum products that now require elaborate catalytic cracking units. University of Michigan researchers have conducted a program over the past four years exploring a range of radiation uses from food sterilization to improved combustion of fuels. And the AEC has invited proposals from industry to build a special reactor for the U. S. Army Quartermaster Corps to irradiate more than 1000 tons of food per month.

Now a new process radiation service has been planned by Isotope Products, a firm specializing in industrial atomic energy applications. Professional consultation and technical assistance on radiation application will be one aspect of this service. Contact with groups working on parallel problems will be maintained and existing work surveyed.

The company has also ordered a radioactive cobalt source that will yield up to one million roentgens per hr. It is planned for use in a radiation pilot plant now reported in the design stage. From this it is expected that the program will lead to the design and construction of individual commercial units for production line irradiation.

HOW TO GET

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Excellent though this engine's performance is, the new line of Caterpillar Diesels will deliver even more power with less down time at lower cost. The Cat D318, for example, is ideal for installation in shovels like the one shown here.

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# NEW MANUAL

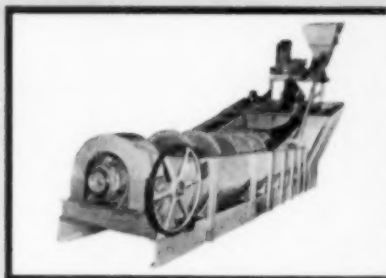
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# More Profitable Goldbricking at Benguet with Unique Slime Flotation Process



- 1 - The combined 3000 ton Benguet ballast mill in the rugged grandeur of the Benguet gold-mining field.
- 2 - Ball mills and bowl classifiers in the cyanide circuit.
- 3 - Tray thickeners in cyanide circuit showing leaching tank associated with the primary slime of the ore.

**AMERICAN CYANAMID COMPANY**

**MINERAL DRESSING DEPARTMENT**

**30 ROCKEFELLER PLAZA, NEW YORK 20, N. Y.**

At the 3,000-ton-per-day Benguet-Balatoc mill of Benguet Consolidated Inc. in the Philippines, primary slimes resulting from gouge material in the vein system amount to 13% of the tonnage milled. Extremely fine and gelatinous, these slimes are difficult to thicken and almost impossible to filter because they form a very thin, impervious filter cake.

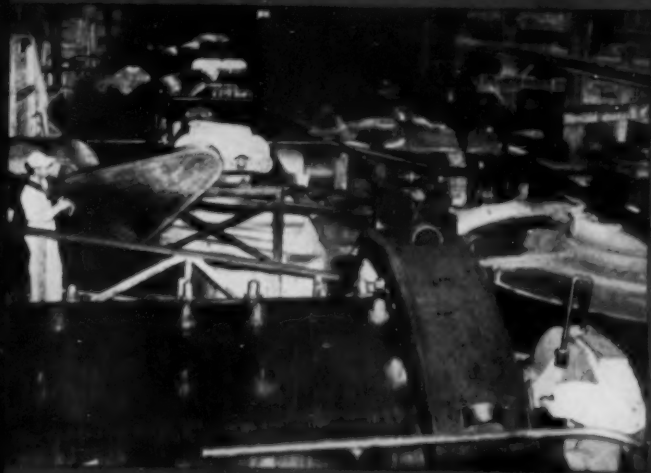
In spite of these extraordinary difficulties, Benguet's novel procedures now recover 79% of the gold in these slimes. After sand-slime separation in spiral classifiers, the slime is passed through a 24" DorrClone at the rate of about 250 tons per day. The underflow goes to cyanidation with the sands, and the overflow to flotation.

Feed to flotation contains about 2.25% of the total values in the original ore and averages 12% to 14% solids. Reagents used include AERO® Xanthate 301 at 0.033 lb. per ton and AERO® Xanthate 350 at 0.046 lb. per ton, with pine oil and soda ash, to scalp out a concentrate running over \$9.00 per ton. Flotation concentrates are fed to the cyanidation circuit for leaching with AERO® Brand Cyanide.

Prior to use of DorrClones in the slime circuit, 5.5% of the total tonnage milled was treated by flotation. With the addition of the 24" DorrClone, approximately 8.5% of the total tonnage milled now goes to flotation.

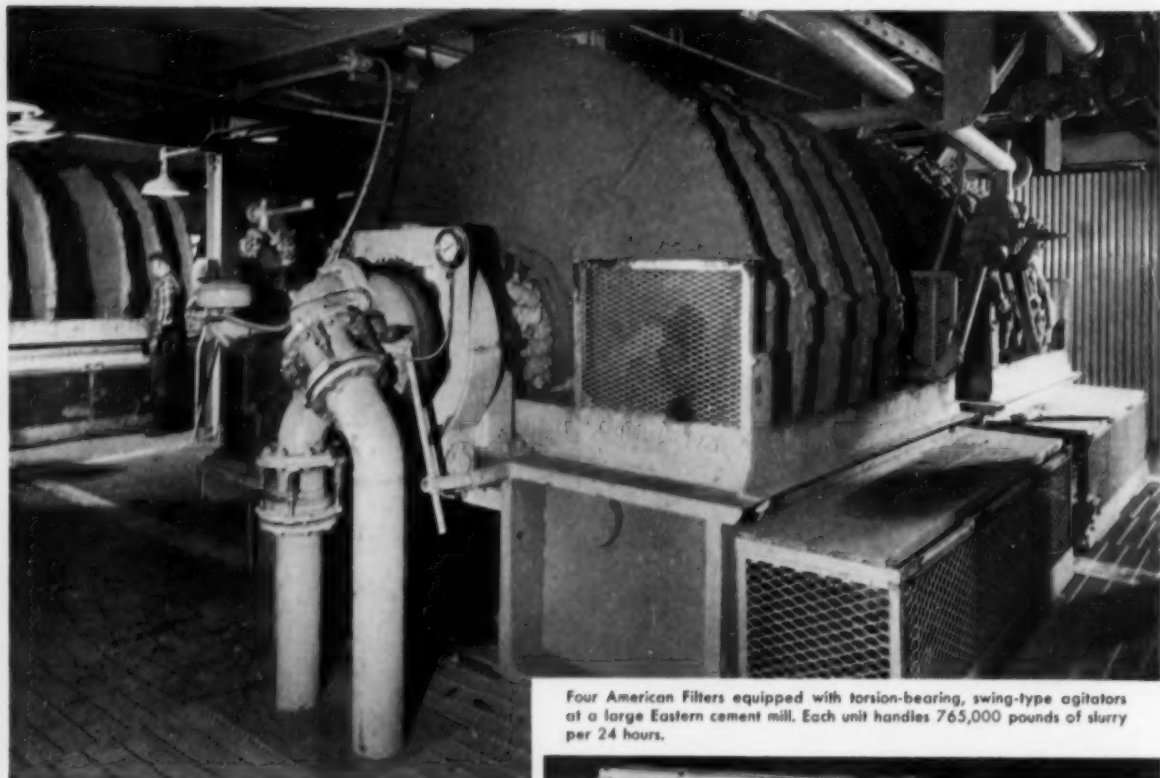
The present method improves precipitation, filtration of final residues is easier and soluble loss is reduced. Fewer pumps are required. There is a marked effect on settling in both primary and secondary thickener circuits, allowing two 50-foot balanced tray thickeners to be withdrawn from the cyanidation circuit. And flotation reagent consumption is slightly less.

Important to the Philippine economy, the post-war resurgence of the Benguet operation has been remarkable. Two independent mills at Balatoc and Benguet were almost completely destroyed during the invasion and liberation of the Philippines in 1941-45. Ingeniously and painstakingly the



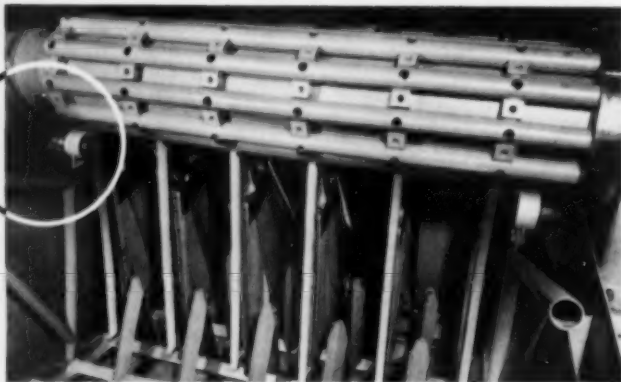
mill was rebuilt at Balatoc with salvaged bits and pieces and operations were resumed until new equipment arrived. The Balatoc mill handles ore from both mines, with Benguet ore travelling through a 13,000-foot tunnel. Cyanamid engineers have been privileged to work with the Benguet staff for many years. Cyanamid has supplied Benguet and Balatoc with its products for over 25 years. A Cyanamid engineer will be glad to share with you his sound operating and metallurgical knowledge. A letter or phone call will bring you prompt service.

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Four American Filters equipped with torsion-bearing, swing-type agitators at a large Eastern cement mill. Each unit handles 765,000 pounds of slurry per 24 hours.

## New Swing-Type Agitator on **AMERICAN FILTER...**



Closeup of the new agitator installed in Filter Tank. Torsion bearings are at left and right just under the main shaft.

Latest development in continuous disc filters is a new swing-type agitator designed by Dorr-Oliver that completely eliminates troublesome stuffing boxes and assures uniform agitation from the bottom of the tank to the slurry surface. Here's how it works.

Vertical picket members are attached to the agitator. These pickets extend up between the filter discs and insure positive, uniform agitation throughout the feed slurry. Torsion bearings located on the inside of the tank walls

support the agitator. These bearings incorporate a special rubber compound, bonded to the bearing support and agitator shaft, that flexes as the shaft oscillates. It is impossible for slurry to enter the bearing.

This new development is typical of Dorr-Oliver's continuing search for improved techniques in wet processing. If you'd like more information on the American Filter with the new swing-type agitator, just drop a line to Dorr-Oliver Incorporated, Stamford, Connecticut.

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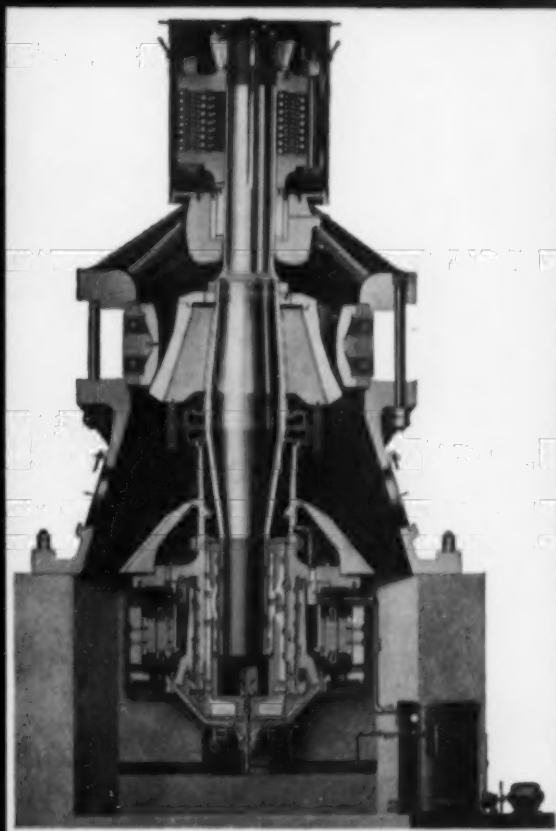
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Cut-away drawing of KVS roller bearing, gearless Type "S" Crusher; low head type for fine crushing.



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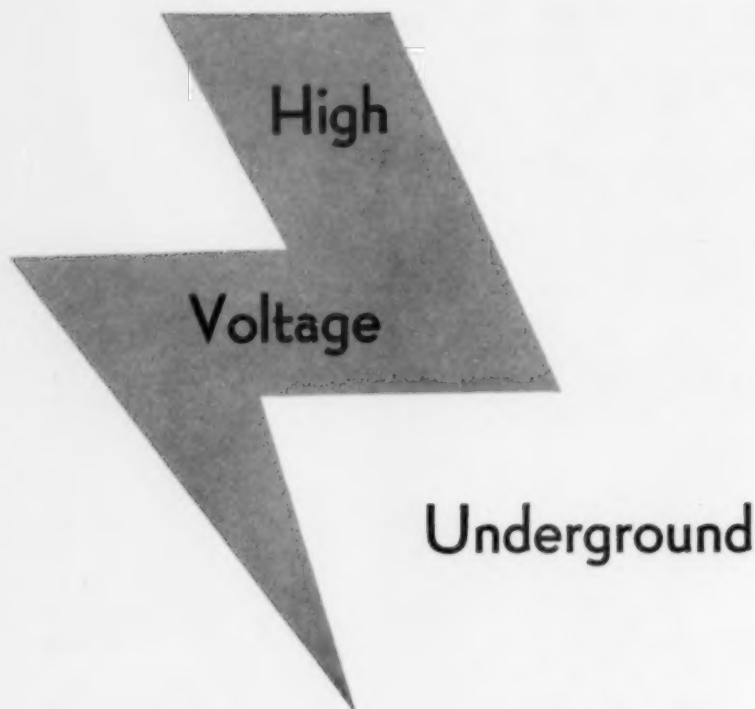
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# Taking



**A** LPHA Portland Cement Co.'s mining operations at Manheim W. Va., produce 750,000 bbl of limestone yearly, averaging 2200 bbl per working day.

Thirteen parallel entries have been driven to date, each almost 30 ft high and about 45 ft wide, extending back 5000 ft to the working faces.

Pitch of the seam from the lowest to the highest entries is steep enough to provide excellent year-round natural ventilation, and this, together with the size of the entries and a good bottom, has allowed face crews to drive right up to the working areas in the family car.

Getting adequate power back to the working areas soon posed a more difficult problem. As a dozen rock drills, two power shovels, and an electrified haulageway moved farther and farther from the portal, it became evident that something more than additional lengths of feeder must be added to the system. The solution, as shown in accompanying pictures, was construction of an underground substation about 4000 ft from the portal.

Three-phase 12,470-v power was readily available from a transmission line running only 2200 ft from the mine entrance. The best method of suspending three NO. 2 A. C. S. R. conductors carrying this voltage required some investigation, however, and Ohio Brass Co. was called in for assistance.

After examining the mine roof, a 20-ft slab of

limestone with up to 900 ft of cover, an O-B representative suggested using standard mine hanger expansion bolts to anchor the suspension insulators required by the relatively high voltage. Materials used are indicated in the accompanying sketch, and pictures of suspension points are also shown.

Suspension units are spaced at 100-ft intervals and total length of lines to the substation is, as already mentioned, approximately 4000 ft.

The substation, consisting of three 150-kva transformers, steps voltage down to 440 v for trailing cables supplying the two power shovels. The station also supplies power to air compressors for the rock drills and to a 125-hp generator set that supplies 250 v dc to the trolley circuit.

Power shovels load directly into 5-ton cars, which are switched by three 8-ton battery locomotives and hauled to the portal in trips of 10 cars by an 8-ton and a 10-ton locomotive. Outside the main haulage portal is a second dumping point for two 5-ton trucks that carry stone from a diesel shovel operating just inside the portal.

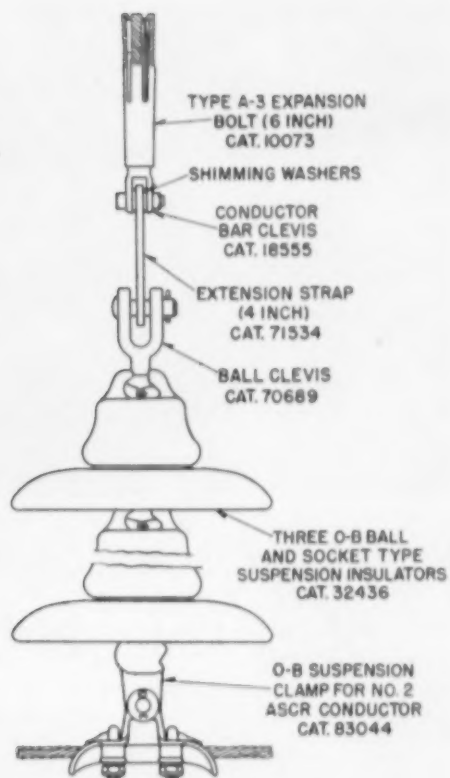
Trips from both inside and outside loading points move on to dump into an inclined hoist that carries the stone into the crusher located in the valley below the mine portal. The two 10-ton skips at the incline are on a continuous cable, the loaded skip pulling up the empty one as it descends to the crusher.

Construction of the underground substation has assured adequate power—and peak efficiency of face machinery—for Alpha Cement's Manheim operation.

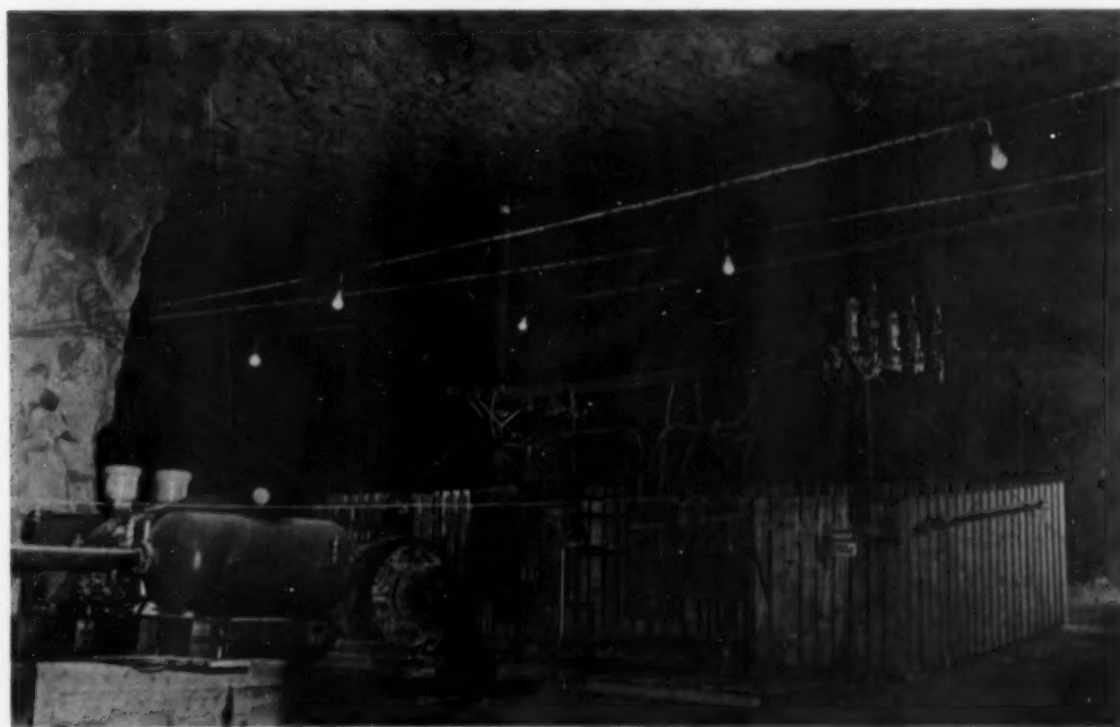
Illustrations and information for this article were supplied by Ohio Brass Co., Mansfield, Ohio.



ABOVE: Looking up at O-B suspension insulators in strain position against the mine roof. Insulators are anchored to roof by means of O-B mine hanger type expansion bolts. RIGHT: Sketch showing construction details of suspension points located at 100-ft intervals along 4000 ft of entry leading to substation.



***Alpha Portland Cement Co. uses unique insulators to carry  
12,470-v lines to underground substation.***



Substation is about 4000 ft from portal and under 900 ft of cover. Three 150-kva transformers supply 440-v power to trailing cables for two power shovels. Station also powers compressors for rock drills and generator for dc trolley circuit.



## Lake Asbestos of Quebec Ltd. Dredges Black Lake in Unusual Mining Project

**I**N one of the largest dredging projects of its kind, Lake Asbestos of Quebec Ltd. is stripping overlying mud and sand from the bed of a lake to reach asbestos orebodies 70 to 200 ft below surface. Black Lake, about two miles long by half a mile wide, was almost overlooked in the search for asbestos in Quebec's ore-rich eastern townships—a search that has been underway there ever since the first asbestos was mined in 1877.



Not until 1948 was the Black Lake mineral discovered. Four years later careful exploration was carried out by American Smelting & Refining Co., parent firm of Lake Asbestos. The search involved more than 75,000 ft of diamond drilling and about 5000 ft of underground work. ASARCO, in its first asbestos mining project, decided to proceed with a dredging and draining program to prepare for open pit mining.

Construction work began in May 1954 with a channel to divert the Becancour River, which now flows into Black Lake. The diversion channel, completed early this year, is approximately 7000 ft long by 100 ft wide. Simultaneously, contracts were let for the construction suction dredge, *Fleur de Lis*, and its steel pipeline to carry dredge spoil to disposal areas.

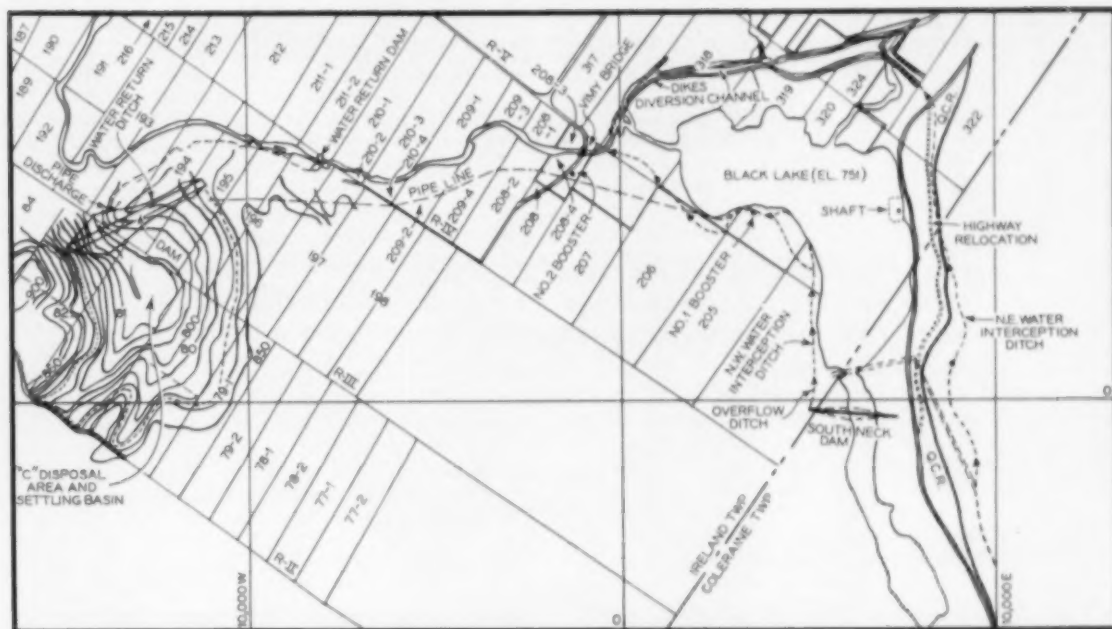
Dredging operations, initiated in June of 1955, are now in full swing. More than 25 million yd of mud, sand, gravel, and boulder clay will be pumped and deposited in a basin-shaped area about four miles west of the lake, and a 4700-ft hydraulic dam has been built to contain the material. Dredge spoil is carried across the lake by a pontoon line 3300 ft long and to the disposal area by a shore line 20,000 ft long. Outlets along the shore line have been put in at 14,000 ft, 18,000 ft, and 20,000 ft.

Dredging will be continuous throughout the year. Ice-breaking facilities have been prepared to maintain operations through the subzero winter months. As dredging proceeds, water in the lake will be lowered as much as 80 ft the first year and perhaps more rapidly in future. Water for dredging will be supplied from a reservoir, constructed at the south arm of Black Lake, by means of a water control structure on the Becancour River diversion channel.

The electric-powered *Fleur de Lis* is 140x40 ft, with a 75-ft cutter ladder, an 800-hp motor for the

Illustrations and information used in this article were supplied by Alco Products Inc.





cutter, and a 6000-hp motor for pumping. Capacity is approximately 35,000 gpm, and the average daily output will be approximately 30,000 cu yd. Electric power is supplied by submarine cable from the Shawinigan Water & Power Co. line at Thetford Mines nearby. Two booster pumps are located on the line, the first equipped with a 6000-hp motor and the second with a 3000-hp motor. Dredge spoil will move in the pipe at 17 fps.

Cost of removal of the overburden by hydraulic means will be much less than if the job were done by draglines, shovels, and trucks. The large volume of material to be removed and the distance of the

disposal area from the site are factors contributing to economies realized through dredging, despite the large initial capital investment required.

Electric-welded steel pipe for the pontoon and shore pipelines was built by Alco Products Inc. and Montreal Locomotive Works Ltd., Alco's Canadian affiliate. The pipe was built on contract for Construction Aggregates Corp., Chicago—agents for Lake Asbestos in construction and operation of the dredging installation. Furnished in 50-ft lengths, it includes 25,000 ft of shore pipeline, 32 in. OD with  $\frac{1}{2}$ -in. wall thickness, and 3500 ft of pontoon line pipe, 30 in. OD with  $\frac{3}{4}$ -in. plate.



# Middle Management Training for Mining Engineers

*Here is a challenge to industry to meet the need for management training for the men now passing from essentially technical work into managerial responsibility . . . And a program to handle the job.*

by John Fayerweather

THE purpose of this article is to throw out a challenge both to industry and to educators—a challenge to meet a crying need for management training among the young mining engineers of our nation, the men from 25 to 35 years old who are passing from essentially technical work into managerial responsibilities. It is the author's suggestion that these men could profit tremendously from the intensive training in management subjects which could be provided by short programs in mining administration. The challenge is to mining educators to provide such programs and to the mining industry to support the programs and to release their men to receive the training they need. Such a proposal clearly requires sound supporting arguments.

## What is the need?

In a recent issue of MINING ENGINEERING, A. C. Dorenfeld asked, "Are Engineers Prepared for Executive Responsibilities?"\* Professor Dorenfeld pre-

\* A. C. Dorenfeld, MINING ENGINEERING, February 1955, p. 143.

sented very concisely and completely the main facts which will explain the need for this sort of management training. These facts will, surely, sound familiar to all mineral engineers.

Undergraduate training of mining engineers is almost completely technical. A thorough grounding in natural sciences and engineering prepares him to deal with the technical problems of mining. On his first job this is usually both essential and adequate. His capacities are stretched to the limit in dealing with the physical problems of getting rock broken and out of the ground. His managerial responsibilities are limited in scope and can be mastered by the common sense and intelligence of a normal man. For the most part they consist of the direct personal relations between a man and those with whom he works on a level or in a survey party. For the first 5 to 10 years while he is in such work the engineer's college training stands him in good stead.

J. FAYERWEATHER is Assistant Professor, Graduate School of Business Administration, Harvard University.

In due time, however, he begins to move up the scale and feel the need for new skills. He becomes a shift boss, a foreman, a superintendent, and eventually a mine manager or rises still further. Because of the great shortage of good men in our expanding industry, advances often come rapidly.

The new skills which men need as they pass to higher responsibilities are considerable. They include such individual business techniques as cost analysis, labor relations, human relations, and price analysis. And more important than these techniques is the learning of such administrative skills as sound judgment, ability to plan ahead, and capacity for dealing with complex problems.

For each individual these needs are a major problem and their acquisition determines success or failure. Two examples will illustrate.

A couple of years ago a young engineer became manager of a small mine in a relatively isolated spot in Mexico. He had a lot of problems with the labor force, union negotiations, and the management personnel. And the whole life of the operation was periodically endangered because it was marginal and subject to the fluctuations of base metal prices. To keep the mine above water he had to cut costs and to do that he had to master the skills of accounting and cost analysis. To keep an assorted group of individuals at the management level working together effectively in an isolated location he had to develop administrative skills—the understanding of how to handle individual men and mold them into a useful operating unit.

As a second example, consider a young engineer who had just taken over as mine captain of a medium-sized operation in Canada. This man's problem came to the author's notice when he was reviewing the mine's labor productivity over an extended period. The mine manager pointed out that there had been a significant drop recently which he attributed to the inexperience of the new captain. He explained there was a lot the captain would have to learn about planning the work and setting things up so everyone would be busy and there would be no waste motion. It is certainly true that directing a large number of men and machines to achieve output is a distinct administrative skill.

There is probably no need to belabor this question of need. Surely everyone has observed individuals going through the transition from technical work to management responsibility. The main question concerns the adequacy of the help they can get in acquiring management skills. And specifically, what function short management programs could perform in this process.

### Three ways to learn management skills

Currently there are three main ways in which engineers learn management skills: by self education, from their superiors, and by participating in management courses. Self education is undoubtedly the most important in magnitude and will always be so. In fact, the author is inclined to regard the second two as merely adjuncts to the basic process of self education. But, this process has been separated primarily to emphasize the extreme to which self education is pressed by the nature of the mineral industry. There are many men who must rely almost completely on themselves in learning management skills because of the isolated locations of their work.

Training by superiors is, and will continue to be, the major aid to men in their self education. Considering the number of practicing engineers and the needs for continued industrial operation, it is clear that most of a man's time must be spent under the guidance of his boss. Furthermore, many of us who are professionally concerned with techniques of training administrators are convinced that practical experience coupled with effective coaching by superiors is the best way for men to get most of their training.

Management courses do, however, have a definite place in the development of managers. At the right time in a man's career they are a highly effective and efficient method for giving a major lift to a man's abilities both in terms of specific management techniques and general administrative skills.

In recent years there has been a tremendous growth in such courses serving many industries. No one knows the exact number of men involved, but according to one estimate it exceeds 2,500 per year, a figure which is probably quite conservative.\* Such

\* *Business Week*, October 23, 1955, p. 186.

a phenomenon is no mere fad. It means that in at least 2,500 individual instances U. S. managements have concluded that it is worth paying good money to take men from their jobs for extended periods and pay for their instruction, frequently at quite high rates. Companies take expensive actions like these only when they can see offsetting future gains.

The mathematics of an investment in such training is very simple. The expenditure of at most a few thousand dollars is rapidly repaid if management actions affecting sales, payrolls, and investments of far greater magnitude can be improved. The chief questions which managements ask concern the benefits the men will derive from the training, and experience has demonstrated that there are specific benefits to be achieved.

First, a man is taken physically from his job for long enough to get a new perspective on it. Second, he acquires new knowledge and new skills, and when he returns to work he is eager to do a better job with this new equipment to help him. Finally, his personality develops from the broadening process of working with a new group of men.

This is just the sort of development which many mineral engineers need. They need almost literally to be pulled out of their holes in the ground and given a chance to see their jobs in proper perspective in relation to the economy and even to society as a whole. Of their need for techniques in such things as labor management, and administrative skills such as capacity for planning, I have already spoken. The value of personal development probably needs no defense. As a man rises in the management scale, success hinges more and more on ability to live with others and effectively direct their work.

At this point it is logical to ask: "What's the problem? Why are you talking about new programs for mining engineers? If there are benefits to be had from such training, let the mining companies recognize them and send their men to existing courses." The answer unfortunately is that the existing programs are not adequate for engineers from the mineral industries. A few mining companies have sent their men to some of them and they have certainly derived benefits in the process. Many of the problems of the mineral industries are, however, distinctive and the existing courses are of little help in training men to deal with them. The typical management program is concerned with manufacturing concerns and the production, financial and marketing problems associated with manufacturing. A mining man can learn a great deal from studying manufacturing problems and listening to manufacturing men, but in the end he will still not have gained new insights on all of his major problems.

To illustrate this deficiency let me comment briefly on a specific program. This program is offered by an outstanding institution, and it is doing an excellent job. It is intended primarily for men with engineering backgrounds, and to that extent it is one of the closest approaches to the mining engineer's needs available. Here are some of the things which a man in this program studies. In the marketing course he analyzes problems in distribution of manufactured products, advertising and promotion programs, and market surveys. In the production course he is concerned with such matters as factory expansion plans, inventory systems, and factory production control.

These and other matters are of vital concern to men responsible for manufacturing and selling consumer and industrial products. But to a mining engineer they are of questionable value. In marketing he is concerned with the analysis of metal prices and the negotiation of smelter contracts—not the promotion of canned goods in supermarkets. In production planning he is concerned with exploration policy and property acquisition, not factory extension. There are clearly relationships between the methods of analysis which one should apply to these problems but often they become so remote that the engineer is lost in trying to find them. I mentioned the problem of promotion in the supermarkets especially because I recall an engineer in the midst of one of these programs pleading with me to explain how that was going to help him when he got back to work.

It seems abundantly clear that the matters on which a young mining engineer seeks help are sufficiently different from those of manufacturing to justify the establishment of a new type of management training program. The exact form which such



a program might take would require considerable thought and doubtless be subject to much debate. To stimulate such thought and debate it may be helpful to set forth at least in broad outline one possible type of program.

First, it should be offered by mining schools and not by schools of business or industrial administration. There are several reasons for this.

Mining companies have worked closely with the mining schools over the years, and close liaison would be vital to any management program in such matters as planning curricula, developing teaching material, and recruiting and screening students. The whole development would therefore be greatly facilitated by attachment to mining schools.

Second, the essential distinctive feature of these programs must be the characteristics of mining operations. Unfortunately the faculties of business and industrial administration schools are very poorly informed on these matters and the core of the teaching groups for such programs would come from men in mining school faculties. Some men would probably be drawn from existing schools of administration, but it would be highly beneficial for them to be taken to a mining school for the actual instruction. In such an environment they would be expected to absorb a greater understanding of the mining industry which would make their instruction more effective.

Finally, most of the mining schools are located in places where trips to mines and visits from mining officials would be practical. Virtually all of the existing management training programs have found that such contacts are a vital part of the training process.

So far as length is concerned, a course of six to eight weeks is suggested. Current courses range from two weeks to twelve months with length dependent upon objectives and the attitudes of the supporting industries. Typically, the longer the course the greater the educational benefit but the smaller the industry interest. The six to eight weeks' course is short enough so that a significant number of companies will release men for the training, and still long enough to permit a sound educational program.

A short program makes the choice of subjects to cover difficult. Out of many possible topics only a few can be included and concentration on four areas which are of greatest significance would appear logical.

**Administrative Relationships:** This includes human relations, organization, personnel administration, and labor relations. All of these subjects are concerned with one main objective—the effective utilization of human beings in a mining organization. The whole area is so large and so vital to operations that it probably should occupy more than a fourth of the time in the program.

**Control and Financial Analysis:** This includes analysis of operating costs, financial arrangements, and the application of statistical methods to mine administration. The emphasis throughout should be on the acquisition of flexibility and skill in the application of figures to direction and control of the management aspects of mining.

**Production Planning and Policy:** The objective here would be to expose the men to the basic production questions at all stages of the mining process and to strengthen their ability to analyze and deal

with them. It would cover, for example, planning the scope and nature of exploration activities, analyzing the feasibility of mining ventures, and working out mining operation plans.

**Economics and Marketing:** These two subjects are grouped together because marketing for miners is so intimately tied to metal prices, and these in turn are so closely related to the total economic situation. The students will need to learn about the basic forces which govern the state of our economy and then move that into an analysis of prices and marketing policy.

No separate area concerned with international matters has been listed. This was no oversight. With the scope of our foreign mining activity growing steadily, one cannot ignore the international aspects of mining administration; but rather it should be made an integral part of all of the courses.

Foreign mining is so important to our industry now that the problems of operation abroad must be second nature to any young man who aspires for a top position. Therefore it seems sensible to deal with such problems right along with the problems of domestic mining. For example, in the Administrative Relationships course the questions of advancement of native workers in Africa would have to be considered; in Cost and Financial Analysis the students should consider the effect of exchange controls on financial arrangements; in Production Planning and Policy, they would have to consider the planning of exploration and production in the light of relative political and economic conditions in various foreign countries, and in Economics and Marketing, time would certainly have to be devoted to the effect of the trends in the international trade in minerals. A very significant part of each subject would probably have to be devoted to foreign management problems, so that far from being ignored, the international side of mining would have major importance.

One final question is that of teaching methods. The program probably should include several approaches, each intended to serve a specific purpose. Leading mining executives as visiting lecturers can give an inspirational and thought-provoking contribution. Expert teachers by exposition and explanation can rapidly advance the knowledge of the men in established techniques such as accounting and economics. The analysis of case problems can increase the men's skills in areas such as Administration Relationships and Production Policy, where the established principles are limited and a man is often on his own. And individual research and writing can be used to foster a variety of personal attributes to managerial success: initiative, thoroughness, and self expression, to mention just three. In any sound program these, and perhaps other approaches, would be carefully admixed to achieve the maximum impact on the student.

The specific program just outlined is subject to question in many respects. It is presented for exactly that purpose. The need for some type of training along these lines seems clear. We have today hundreds of young engineers who need and are seeking skills to handle management responsibilities. Determining the specific ways in which these men can best be helped requires a great deal of thought. It seems time to move ahead rapidly to crystallize a real program which will effectively contribute to the development of capable managers and executives for our mineral industries.



**I**N U. S. underground mines concrete work is not widely used. Timber and steel are cheaper, and there are few serious water problems. But in the Union of South Africa men dig deeper, more persistently, and probably more profitably than anywhere else on earth. Some gold mines near Johannesburg are below the 10,000 level and employ as many as 35,000 natives on a single property. Underground substations, pump chambers, and air conditioning plants have capacity to serve small cities. The complexity and extent of underground operations and the heavy subsurface water flows, especially in the new Free State gold fields, require heavy concrete installations.

One hundred and twenty miles west of Johannesburg is a project of particular interest—the underground pump station of Stilfontein Gold Mining Co. near Klerksdorp in the Transvaal. Here about 1300 cu yd of Prepakt concrete were placed in a pump station 3000 ft below surface.

By South African standards, water control in this mine is not difficult. Shafts and workings are relatively dry and humidity is kept at a comfortable level with the aid of moderate grouting and good ventilation. Pumping requirements are about 1000 gpd. To simplify pump maintenance problems, water is passed through a series of concrete settling basins and sludge separators before delivery to the pumping station. These installations are all about 3000 ft underground.

Shaft space, however, is a bottleneck. Crushed coarse aggregate, sand, and cement for mine concreting are lowered down the shaft to the operating level, hauled in wheelbarrows or mine cars to the mixer, and poured in the conventional manner. One of the principal disadvantages of this arrangement is that considerable time is required for hoisting materials. On small pours this may be insignificant, but on projects requiring several hundred cubic yards of concrete the loss in shaft operating time is very important.

A further difficulty is that mines are staffed to perform routine and maintenance construction, but not heavy new construction. From a personnel standpoint, it would be convenient if large new construction projects underground could be awarded to independent contractors in much the same manner as are major surface installations. The main difficulty with this arrangement has been that in the past all the contractor's material had to be handled down the shaft, creating an awkward division of responsibility. The importance of this problem will be obvious in view of the fact that movement of materials on a lift often has to be scheduled several days in advance.

Using a Prepakt installation in place of concrete appeared to overcome these difficulties. Forms could be filled with coarse aggregate consisting entirely of waste mine rock taken directly from the workings. The rest of the necessary concrete materials—sand, cement, water, and admixtures—could be combined in a surface mixing plant to form a slurry and pumped down the shaft and into the forms to solidify the preplaced coarse aggregate. Once form materials and equipment were in place at the job level, the contractor would need shaft time only for transporting personnel at normal shift-change periods.

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## Placing Concrete

### in a Deep

### Mine

by Bruce A. Lamberton

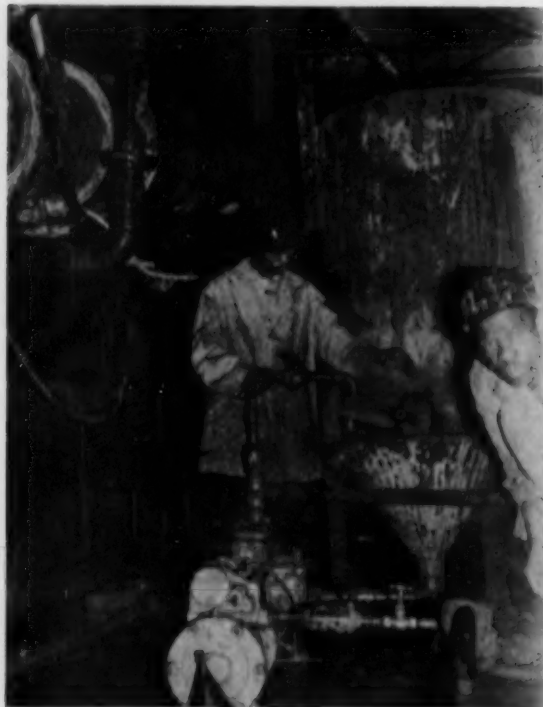
When aggregate was prepared for the Stilfontein mine, the waste mine rock was passed through a trommel-type wash screen immediately before placement in the forms. This removed  $\frac{3}{4}$ -in. material and cleared rock particles of surface dust so that an ideal bond with the Prepakt mortar was insured. Coarse aggregate ranged in size up to pieces as large as a man could comfortably lift. Mortar was mixed on the surface and delivered down the shaft through a 1½-in. pipe, which was used during shaft sinking for pressure grouting and was left in place for any further grouting that might be required during development work.

At the start of this project, excavation in the pump chamber was completed only as far as the adit from the settling basins. As concreting operations on the shaft end of the chamber progressed, continued excavation was necessary to supply coarse aggregate and to prepare the chamber for lining. The chamber was long enough so that blasting at the far end did not disturb concreting operations. Development operations in the pump chamber were actually completed about the time the wall lining reached the halfway mark. A continuous supply of coarse aggregate was thus available right at the job site and, if necessary, could have been supplemented from mining operations in nearby workings.

As might be expected, several difficulties were encountered in putting theory into practice. Perhaps the least of these was the gradation of coarse aggregate. Stone actually ranged from about 1 in. to more than 12 in., but with a deficiency of smaller sizes so that the void content ran about 45 pct. This is a rather high percentage for aggregate with such broad gradation limits. The only effect was to increase cement requirements beyond those anticipated, since the void content originally estimated was about 38 pct. The strength of the concrete in place, as measured by a Schmidt rebound hammer, did not seem to be affected. Under the ideal and constant conditions of temperature and humidity prevailing, durability was not a significant factor.



Materials for intrusion mortar were blended in a mixing tub and dropped to an agitator from which the slurry was carried by gravity through a 1½-in. flanged pipe to a final agitator on the working level. It was remixed here before delivery to forms by a small mortar pump (left).



**Mortar to Prevent Plugging:** A second and far more important problem was mortar delivery. A variety of mixes were tried using straight portland cement, pozzolanic cement, and a mixture of portland cement and fly ash, in combination with Intrusion Aid and several blends of sand. It was found that unless caution was exercised in design and preparation of the mix, line plugs would occasionally develop between the 2500 and 3000 levels. Removal of plugged pipe sections naturally caused interruption of shaft operations, much to the discomfort of

both the contractor and the mine operator. Eventually, however, a satisfactory mix was developed using approximately 2 cu ft of blended sand to one bag of pozzolanic cement, 1 pct of Intrusion Aid by weight of the cementing materials, and a water-cement ratio of about 0.51.

The principal functions of Intrusion Aid in this particular instance were to increase fluidity, reduce bleeding, retard set, and cause a slight expansion of the mortar in the aggregate mass during set to counteract setting shrinkage. Intrusion Aid produces a cohesive slippery mortar, much less susceptible to line blockage than normal sand-cement grout, but without the considerable reduction in strength resulting from the use of Bentonite, a common mine grouting admixture. Under the severe conditions existing here, the use of Intrusion Aid was considered absolutely essential.

Mix control was maintained by the use of standard grout flow cones, one at the mixing plant on the surface and a second at the lower end of the delivery pipe in the pump chamber below. Flow cones are used to determine the time of efflux of a measured quantity of mortar through a machined orifice. Time of efflux in this particular case was held to a variation of  $\pm 1$  sec.

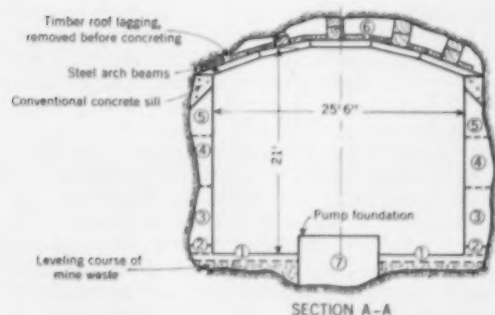
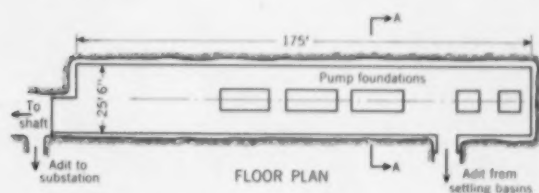
Construction of the floor varied from the usual Prepakt procedure. The floor of the original rock chamber was filled to a level about 6 in. below final grade with mine waste, including fines removed during rock washing procedures. A 6-in. layer of clean aggregate was placed on top of this leveling course of waste rock and was solidified by injecting Intrusion mortar through inserts which were worked down into the clean aggregate layer as far as the leveling course. The mortar surface was then

smoothed off to produce a surface satisfactory for normal use.

**Sequence of Pours:** The length of each pour was generally about 30 ft. Floor and curb sections were constructed in advance of wall pours, which in turn were constructed in advance of the ceiling. By advancing construction stages in this manner, a smooth working platform was always available for erection of scaffolding and wall forms and for rock handling operations. Wall lining was essentially completed up to the adit from settling basins at the time construction of the roof lining was started. During development work steel arch beams on conventional concrete sills were placed in the pump chamber. Forms for ceiling lining were supported by scaffolding from the floor and were kept to line and grade by clamping to the steel arch beams. Tubular steel scaffolding was adjusted to proper elevation and lowered for stripping by means of screw-type jacks. Timber lagging between the steel arch beams and the rock roof was removed immediately prior to ceiling concreting. Pump foundations were installed last.

Ceiling construction was difficult only because placing of the coarse aggregate presented something of a problem. Steel arch beams were on 5-ft centers. Three of these roof sections, a total of 15 lin ft of lining, constituted a single pour. Coarse aggregate, after being passed through the rock washer, was carried to a builder's hoist which elevated it to the level of the arch beams. From this point it was carried by native labor back into the area between the forms and the rock roof. Overbreak, above the top of the steel arch beams, was sufficient to permit men to crawl through to place stone. Roof sections were placed in alternate pours of 15 ft each to economize on form use and to permit maximum utilization of men and equipment.

For successful completion of this work, involving the placing of about 1300 cu yd of concrete, too much credit cannot be given to the management of the Stilfontein Gold Mine, without whose wholehearted cooperation development of this technique



Pump chamber in mine of Stilfontein Gold Mining Co. in Transvaal, Union of South Africa. Circled numbers in Section A-A indicate sequence of concrete placement.



Lift joint of curb appears in foreground. Protruding aggregate produces good bond to succeeding lift. Absence of small size aggregate (see upper left) increased cement requirement but no effect on strength was noted.

would have been impossible. Construction problems of considerable difficulty were encountered and overcome and it is hoped that the methods developed may prove useful in other types of underground work. By these methods, wasteful double handling of coarse aggregate—from the working face to the surface and back again—is eliminated. Mining crews have free access to the working face without interruption by long lines of mine cars carrying concreting material. The Prepakt method, by its very nature, assures a tight bond between the lining and the original rock face, eliminates the necessity for crown grouting, and provides a dense, impermeable lining at a saving over conventional methods.



Wall lining was constructed in three lifts between curb section and conventional concrete sill which supported steel roof beams. Trammel screen in foreground was used to clean coarse aggregate of surface dust.



# Soils in Geochemical Prospecting

by Harry V. Warren and Robert E. Delavault

**G**EOCHEMISTRY in all its branches is playing an increasingly important part in the business of mine finding. Although geochemical studies were commenced more than 50 years ago, interest in this subject did not become widespread until the late 1930's when in Scandinavia and the U.S.S.R. a whole series of investigations were initiated. Unfortunately for those in North America, the results of these investigations have only recently become available. In Canada and the U.S. geochemistry as a serious mine finding tool dates back only to the period following World War II.

This article deals primarily with soils, which have found widespread acceptance as a useful tool in geochemical prospecting. Actually soils vary greatly in texture, structure, profile, and mineral background. Soil sampling poses no hardship for normal intellects, but it does assume an elementary knowledge of soil science and of the chemical problems involved in determining the absolute and relative amounts of a particular element in any particular soil.

**Soil Defined:** Many of the technical terms used in soil science are everyday words that have been given precise and occasionally unusual meanings. Thus a writer in the U.S. Department of Agriculture wisely draws attention to the fact that "such words as *loam*, *texture*, *structure*, *heavy*, *light*, *profile*, *horizon*, and even *soil* may have a deceptive familiarity to the layman using the language of soil science. . . . Thus there is no escape from a certain amount of double language."<sup>1</sup>

So it is that the term *soil* has different connotations to geologist, engineer, and agronomist. In one of the more recent textbooks on geology the authors write: "The term *soil* is sometimes applied erroneously to mantle of any kind, but properly it refers only to the part of the mantle which has been so decomposed and otherwise modified that it supports rooted plants." (Ref. 2, p. 55.) These same authors describe mantle as "the widespread cover of loose material on the bedrock." (Ref. 2, p. 43.) After describing residual and transported mantle, they make specific mention of the former: "Evident relation to the underlying rock, shown by almost insensible gradation into it, is characteristic of mantle formed in place." (Ref. 2, p. 55.) To the geologist mantle becomes *soil* with the advent of rooted plants.

The engineer has a totally different conception of soil. Here are two engineering definitions: "As the word *soil* is used in an engineering sense, it may be described as that portion of the earth's crust which is fragmentary, such that some individual particles may be readily separated by the agitation in water of a dried sample. . . . It has been derived from solid rocks by natural processes of chemical and physical disintegration and may have been subsequently modified by atmospheric or biological agencies."<sup>2</sup> "The word *soil*, in engineering term-

inology, refers to all of the unconsolidated mineral material at or near the earth's surface, plus the air, water, organic matter, and other substances which may be included therein."<sup>3</sup>

On the basis of the above definitions a sand dune, a layer of volcanic ash, and a moraine would all be soil to an engineer. However, they would be transported mantle to a geologist or soil scientist unless, of course, rooted plants were present.

All of these definitions fail to mention a factor of major significance to anyone dealing with soils, particularly those engaged in a search for buried ore deposits. Rocks and mantle tend to be homogeneous in all directions. In contrast, soils are vertically heterogeneous. Hans Jenny writes as follows on this aspect of soils:<sup>4</sup>

To a certain extent, many geological formations such as granite, loess, limestone, etc., are macroscopically isotropic, i.e. the physical and chemical properties are independent of direction.

All soils are anisotropic. The spatial distribution of soil characteristics is not randomized but depends on direction. Along a line extending from the surface of the soil toward the center of the earth—arbitrarily denoted as Z-axis—the sequence of soil properties differs profoundly from that along lines parallel to the surface. The soil has vectorial properties.

In the language of the pedologist, the anisotropism of soils is usually expressed with the words, "The soil has a profile."

The terms *isotropic* and *anisotropic*, even when preceded by the term *macroscopic*, are not well chosen for general use because they are widely employed by geologists and mineralogists with an entirely different meaning.\*

\* The terms *isomeric* and *anisomeric* should be acceptable to geologists, engineers, and agronomists alike, although chemists use them with a highly restricted meaning. The two words appear in both Webster's and the Oxford dictionary and they have not yet been used, to the best of the writers' knowledge, by geologists, engineers, or agronomists.

Soils are characterized by changes in appearance or composition along a vertical direction, and this leads to a recognition that soils are generally layered. The layers are termed *horizons*. A vertical cross section through these horizons down into the underlying parent material is called a *soil profile*.

Weathering is most vigorous at the surface. Deeper in a soil there are different stages of weathering, and a tendency toward accumulations of specific salts and organic compounds at different layers. These layers or horizons frequently differ from one another in color and appearance. Because in addition to its parent material soil is the product of many factors including climate, living matter, relief, and time, it is not surprising that there are literally many thousands of unique kinds of soil in the world. Pedologists have taken great pains to classify soils. Detailed classification is not practical in a paper written primarily for those interested in exploration. However, a bare outline of soil classification is essential if the results of workers in various parts of the world are to be compared and assessed.

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Earlier American soil classification sets up two main soil groups, the pedocals and the pedalfers.<sup>6</sup> This has since been modified, but the concept suggested by these terms can usefully be employed by geologists. The pedocals are characterized by the presence of lime carbonate, in some horizon or layer, in higher percentage than in the parent material. The pedalfers have no such layer, even where the soil has been derived from parent material rich in lime carbonate, but do contain an horizon in which iron and alumina have accumulated. The pedocals were further divided into many subgroups, four of which are of particular interest to geochemists: the chernozems, the chestnutearths, the brownearths, and the greyearths. In these there is a progressive decrease in organic content. They are the soils of the grasslands rather than the forests. The pedalfers are divided into a multitude of subgroups, of which five great subgroups are of special interest to geochemists: the podsoles, the grey-brownearths, redearths and yellowearths, ferruginous laterites, and prairieearths, all but the last named supporting forest growth under normal conditions. Prairieearths represent a transitional type between the pedalfers and the pedocals. In general the pedalfers are soils developed in humid areas: the podsoles are indigenous to colder climates and possess a thick humus horizon, and the grey-brownearths, the redearths and yellowearths, and the laterites occur in increasingly warmer climates and exhibit less and less humus and more and more leaching.

Normally soil profiles contain three main layers, which may or may not be subdivided into: 1) an A horizon where leaching or eluviation tends to take place; 2) a B horizon where accumulation or illuviation is apt to be most evident; and 3) a C consisting of the parent material from which the soil was formed. In soils which are just developing from mantle that is young or immature soils, one horizon may be missing, usually the B.

The A and B horizons are in turn subdivided into various layers of which, for the purposes of this paper, it is necessary to mention only the  $A_0$ , organic litter; the  $A_1$ , a good mixture of mineral and organic; and the  $A_2$ , typically grey and impoverished.

Most soils contain mineral particles of different sizes or diameters. These variously sized particles are known as *soil separates*, and an analysis of a soil to determine the proportion of these separates is called a *mechanical analysis*. Names and sizes of the more common separates are as follows:

Separates	Diam. Mm
Gravel	2.0 and larger
Coarse sand	2.0 to 0.2
Fine sand	0.2 to 0.02
Silt (flour or fine pulverulent)	0.02 to 0.002
Clay (sticky characteristics)	0.002 and smaller

The three main separates are sand, silt, and clay. A classification based on the percentages by weight of these various components is known as a *textural classification*. From this textural classification are derived such terms as *clay*, a soil containing over 30 pct clay, and *loam*, a mixture of separates in which no one separate or group of separates is outstanding; the stickiness of the clay and the finely pulverulent (floury) nature of the silt are balanced by the nonsticky and mealy or gritty characteristics of the fine to coarse sands. Usually, but not always,

loams have a high organic content. Soil texture refers to particle size.

Soil structure refers to the arrangement or grouping of these particles. Man, by chemical and physical treatment, can alter structure materially but not texture. The usual names applied to soil structures are largely descriptive: *single grain*, *massive*, *granular*, *nutty*, *blocky*, *fragmental*, *columnar*, and *platy*.

**Sampling and Analyzing Soil Samples:** It may seem paradoxical to state that when a soil sample has been taken the task of learning the contents has only commenced; nevertheless, this is a fact, and one not always appreciated.

Soils frequently consist of particles of various textures and contain varying amounts of organic material. Because pedologists have been investigating the heavy metal content of soils for a long time it would seem natural to go to them for advice on the best way of sampling a sample of soil. The normal procedure of the pedologist is useful and enlightening. However, on occasion it may be a mistake to treat a soil, collected with the intention of seeking buried ore, in the same way it would be treated were it collected with the object of assessing its feeding value for plants, and more particularly cultivated plants. The agricultural pedologist is primarily interested in the amounts of nutrients readily available to plants, or in general in those nutrients that can be extracted by mild reagents. The geologist, on the contrary, is looking for any token of the mineral content of the parent rock and must be prepared to use whatever treatment is necessary, whether or not such treatment parallels the extractive capacities of one or more plants.

Plants feed on ions that are held by surface binding, most commonly to soil colloids. Consequently agricultural scientists in most instances prefer analyzing smaller soil particles, such as silt or clay, which control the bulk of these ions. Furthermore, these ions are immediately available to plants because they are exchangeable; a mild reagent able to take these ions into solution and possessing a high concentration of exchangeable ions will give the best idea of a soil's possibilities with respect to heavy metal nutrients. Nevertheless, in many soils the ions referred to above account for only a portion of the total heavy metal content of a soil. The total heavy metal content of a soil may tentatively be split into the following components, according to comparative ease of extraction:

1) Free metal ions, usually a comparatively small percentage of total metal present, and subject to wide variations. These ions can be extracted by pure water.

2) Metal ions loosely bonded to clay and organic matter and subject to exchange. These ions are most important for the needs of vegetation. They can be extracted by cold treatment with a saline solution of pH near neutrality.

3) Metal ions tightly bonded to organic material, possibly by chelation or by having penetrated clay particles. These ions are not subject to exchange if mild reagents are used. They are not usually available to plants and are therefore of minor interest to agriculturists. Strong acids are sometimes needed to extract them.

4) Metal in secondary oxides or carbonates which may represent supergene alteration of original ore minerals or products of sulfate weathering. This metal may be extracted by mild acids.

5) Metal contents of primary silicate or oxide minerals. These may be very important in the case of some elements, for instance, nickel. These are usually released by strong acid attack and indeed may safely be considered as released only after total destruction of the silicate lattice by carbonate fusion or some form of hydrofluoric acid attack.

6) Metal content of free sulfides. Free sulfides are not normally present in soils, but where they are they may add materially to the total metal content. This may be particularly important above mineralization. Some sulfides are attacked only slowly by *aqua regia* after very fine grinding and will stoutly resist attack where they are in a coarse natural state.

In practice, soil scientists frequently find it eminently satisfactory to use a method of extraction which collects only components 1 and 2 of those listed above. Particularly good illustrations of the use of these components are provided by Chisholm<sup>7</sup> and Bloom.<sup>8</sup>

Lakin, Almond, and Ward<sup>9</sup> of the U. S. Geological Survey have described four more potent methods of attack varying from the use of 1/7 nitric acid to equal parts of hydrofluoric and concentrated nitric acid. Another convenient practice involves fusion with potassium bisulfate; this is faster, does not entail refluxing of reagents, and makes less fumes. The more rigorous attacks mentioned above would extract all six components listed previously and the less vigorous would extract intermediate amounts.

If soil analysis is not conducted in connection with plant needs there is no special advantage in using only the silt and clay fractions in a soil, particularly if these fractions can be obtained only by tedious sifting through silk or nylon. It is sufficient to take material less than 2 mm in size. The writers themselves have on occasion used even coarser material without noticeably affecting results. Lovering, Huff, and Almond<sup>10</sup> have also demonstrated that size of particles may not influence soil analyses too much. At the University of British Columbia W. H. White's technique<sup>11</sup> is adopted, and well dried soil is screened through ordinary screen wire gauze.

Because of the large differences between anomalous and normal contents of any particular metal in a soil, it is quite acceptable in the opinion of USGS geochemists, and indeed many others, to measure soil samples by volume. This, however, is only practical if the soil samples being compared have similar textures.

In the University of British Columbia geochemical laboratories it has been found useful to subject soils to red heat before sampling, usually 1 hr at about 1200°F. This treatment has certain advantages. It destroys organic material, which can be decidedly annoying later on because of its tendency to stabilize emulsions of some of the organic reagents used in analyses. It also indicates approximately the amount of organic material present in a sample, oxidizes any sulfides present, and alters the lattices of at least some silicates, thereby making them susceptible to attack by ordinary acids.

It may be gathered from the above discussion that there are many recipes for attacking soils. Iron oxide that has been heated becomes much more difficult to dissolve in acids, and in order to bring into solution organic material ash or soil colloids rich in iron it seems necessary to use some strong treatment. At the University of British Columbia refluxing is continued for 1 hr in boiling normal

sulfuric acid, which has the further advantage of emitting no acid fumes. Refluxing and safe handling are assured by using large tubes 1 in. diam and 1 ft long, slanted outwards so that their tops are well outside the direct flow of heat. Sulfuric acid is a sufficient solvent medium even for lead because the amounts involved are very small, and indeed lead sulfate is more soluble in sulfuric acid than in water. Actually a solubility of 0.0001 pct means 1 mg—or 1000 gammas—per liter, corresponding to 20 gammas in 20 ml, the smallest volume likely to be encountered in treatment of 1 g of soil. Samples abnormally high in lead can always be handled by taking a smaller sample of soil or by increasing the volume of acid.

Readers are referred to standard works on chemical methods such as Sandell<sup>12</sup> or Lakin, Almond, and Ward<sup>9</sup> or to one of the other references at the end of this paper. Colorimetric methods are commonly used, the colored compound being obtained as a spot on filter paper or as a complex that can be gathered in a small volume of some organic solvent. Paper chromatography may be useful in separating various metals for identification. In general it is now possible in a 1-g sample of soil to detect normal contents of most elements and abnormal amounts of even some elements that usually occur in amounts too minute to be detected. In some areas judicious use of pathfinders may simplify sampling and analysis of soil: molybdenum or zinc for copper and arsenic for cobalt are examples of elements that have shown possibilities as pathfinders.

#### Normal Contents of Some Heavy Metals in Soils:

It will now readily be understood that many factors are involved in determining the normal and the abnormal amounts of heavy metals in soils. The parent material, the soil group, the soil horizon, the soil texture, and above all, the method of extraction determine the amounts of elements found in a soil.

Unfortunately, although there is a wealth of material on the heavy metal content of soils much of it is unrelated. Different workers have been working on different problems: agriculturists are usually concerned with deficiencies in soils, whereas geologists are primarily interested in abnormally high contents. Winogradow,<sup>13</sup> who has assembled the greatest amount of data, does not describe in his book the method or methods of extraction used for copper, but he is careful to give soil group, soil horizon, usually the texture, and sometimes the parent material. Geochemists of the USGS, who have made such a valuable contribution to knowledge of soils in the U. S., usually are scrupulously careful to give the nature of the parent material, the texture of the material analyzed, and the method of extraction but only occasionally mention the horizon sampled or the soil group involved. Fortunately the accompanying descriptions are often so clear it is possible to deduce the soil group.

With all these reservations it is with some trepidation that the present writers now give a few examples to illustrate the previous discussions.

In British Columbia Clark<sup>14</sup> studied the copper content of 38 soils ranging from degraded chernozems to grey wooded and podsollic. The parent material in all cases was transported material deposited either by water or ice. Using a rigorous attack, perchloric and hydrofluoric acid, he found that in many instances there were marked differences, usually deficiencies, in the A, or the B horizons, and this in spite of the fact that the A and C horizons

where they were taken collectively did not differ significantly in copper content, which ranged from 12 to 98 ppm of copper and averaged about 40 ppm. Representative samples of these soils were then tested for their readily available copper by means of a 0.1 N. hydrochloric acid attack. The great majority of these soils were of a loamy texture and had a copper content ranging from 0.85 to 2.72 ppm, but half lay between 1.0 and 2.0 ppm. In short, variation in the method of attack showed that somewhat less than 5 pct of the copper in these soils would be obtained by a weak attack. The copper content of the various soil horizons was then studied, and in virtually all cases at least one portion of the A horizon, usually the lowest part, was found to be significantly lower in copper than the B or C horizons.

Lowering, Huff, and Almond<sup>10</sup> showed the possibilities of using soil as prospecting tool. Analyses were made from soil above oxidizing ore, from soil above unmineralized rocks, and of alluvium derived from an ore area and from a barren area. Soil from the oxidized zone, that is, residual soil, ranged from 160 to 16,000 ppm copper. Residual soil from unmineralized rocks usually ran from 40 to 80 ppm. Transported soil, alluvium, would normally contain from 15 to possibly 60 ppm of copper, whereas as far away as 1.4 miles down stream from mineralization an assay of 300 ppm was obtained. Thus in this instance 300 ppm of copper in a soil derived from transported material would be of real interest to a prospector, whereas with a residual soil a much greater concentration would be needed before any economic significance could be attached to it. The above analyses were carried out both by a field method, using hydrochloric acid as a solvent, and by a laboratory method, using aqua regia as a solvent. In this connection it is interesting to observe that except in the case of the very high assays the laboratory results are usually two to three times as high as the field results. The authors working on a project in southern Idaho in a dry area with grey-earth residual soils from a B-C horizon considered only samples above 1400 ppm in copper to be anomalous. In this case only —200 mesh material was analyzed and a sulfuric acid extraction was used.

Winogradow<sup>11</sup> lists many hundreds of soil analyses from all over the world without stating the method or methods of extraction used and without stating whether or not they are derived from transported or residual material. However, a few points do emerge from all the data.

Redearths, and yellowearths whether from the U.S.S.R. or the U. S., are apt to be higher than normal, i.e., greater than 50 ppm of copper in one or all of their horizons. Marsh soils, peaty A horizons, and wet soils are frequently found to have less than 10 ppm of copper. The remaining soils most commonly run from 10 to 50 ppm of copper, the finer textured material running higher than coarser, and soils from basic rocks higher than from acidic. Both American and Russian pedologists have compared the copper content of various soil horizons under various conditions, and all that can be said is that in most soils there is no fixed rule for the distribution of copper in the different horizons. In general there are no great variations. However, in many podsollic soils the A<sub>1</sub> horizon, consisting of leaf litter and much humus, is often much higher in copper than the A<sub>2</sub>, the layer where maximum leaching occurs. On the basis of biogeochemical

observations, this may well be because the copper content of the ash of many species of trees parallels the copper content of the soil: some species are considered accumulators. Thus in the majority of cases the A<sub>1</sub> horizon can be collected with other horizons, or in lieu of them, and no problems will arise. In Canada, however, where podsollic soils are common, misleading results could readily be obtained by sampling to a constant depth because it would be quite possible by this method to obtain half the samples in an area from an A<sub>1</sub> and half from an A<sub>2</sub> horizon.

Before leaving the subject of copper in soils the recent work of Almond<sup>10</sup> should be mentioned. To illustrate a new analytical technique he analyzed fresh rock, weathered rock, and soil derived therefrom for copper. In general basic rocks and the soils derived therefrom are higher in copper than are acid rocks and their derivatives. Soils may contain from four to six times as much copper as the rock from which they are derived or they may contain only half. Whether or not a soil contains more or less copper than its parent rock probably depends primarily on climate, vegetation, and topography; any attempt to set up normals at the present state of knowledge would be premature.

Much that has been said about copper might equally well be said about zinc. However, zinc is more abundant in soils, it tends to be more concentrated by plants, and it is more soluble than copper. It is not surprising that it is more difficult to assign normal figures for zinc than it is for copper.

On the basis of the many valuable reports from Winogradow and from the USGS, and from their own experience, the authors would expect the zinc content of a normal soil to be five to ten times that of copper. The zinc content of vegetation is likely to be much higher than the copper content. It is not unusual for the leaves or young twigs of trees to carry 1 to 2 pct zinc in their ash. This is 10,000 to 20,000 ppm, and it takes little imagination to see how a soil which contains 20 pct of organic matter—a common occurrence in the A horizons of some podsollic or grey wooded soils—will have a relatively high zinc content. Twice during the 1955 field season the authors have seen a series of samples taken on a traverse—one in New Brunswick and one in the Yukon—where zinc contents of about 2500 ppm in a couple of samples raised undue expectations; the normal backgrounds ranged from 100 to 350 ppm. In one case drilling was actually carried out to the disillusionment of all concerned. A study of the samples was enough to reveal that the high samples, taken at constant depth, were composed almost exclusively of A<sub>1</sub> horizons, whereas the remainder were probably A<sub>2</sub> or B horizons. Such extreme cases may be rare, but they serve to point out that soil sampling should be directed by those with experience and that in any area each soil testing problem should be treated on its merits. Winogradow<sup>11</sup> lists the zinc content of various horizons of many soil groups; the great majority run between 25 and 100 ppm, the podsollic types tending to be lower than the others. Unfortunately, neither the parent material nor the method of extraction is mentioned, so comparisons with the results obtained by U.S. geologists are not possible. U.S. geologists have used virtually every known method of extraction varying from ammonium citrate to hydrofluoric and perchloric techniques. Many excellent papers have been published showing results obtained by



using these methods, but pedological and geological variables are too numerous to permit normals to be established for various textures, horizons, and groups of soils, to say nothing of their derivation, residual or transported, or their parent rock, basalt, monzonite, or limestone. Limestones and related sediments frequently carry one tenth of a percent of zinc as a normal constituent. Thus in these areas 1000 ppm of zinc can be perfectly normal for a soil which has no ore significance. On the other hand, Holmes<sup>10</sup> reports that U.S. soils rarely exceed 100 ppm and Hawkes and Lakin<sup>11</sup> in an area in Tennessee consider that 300 ppm zinc in a clay from an A-B horizon of a residual greybrown earth (?) derived from limestone is normal, amounts of zinc over 500 ppm appearing to have geochemical significance. Huff has already pointed out that "in areas covered by till or other glacial deposits any geochemical anomalies will be radically different from those developed on residual soil."<sup>12</sup> In general it may be expected that the zinc content of soils derived from transported material will be lower than that from residual. However, in either case whatever vegetal cover is involved may well have a significant and possibly vital effect in determining the normal zinc contents of a soil.

Much less is known about the lead content of soils than about that of copper or zinc. Lead is much less abundant than copper or zinc in vegetal matter and has much less tendency to migrate. Consequently soils derived from transported material are much lower in lead than those of a residual nature, other factors being equal. It is not unusual for residual soils to run several hundred parts per million of lead without indicating more than the presence of unimportant amounts of this metal in the underlying rock. Nevertheless, in spite of such problems some soils can provide geochemical anomalies of value in a search for ore.

On the strength of hundreds of analyses of soils in the Pacific Northwest using a normal sulfuric acid attack (an attack which in Canadian soils extracted as much molybdenum as would normal caustic soda) the authors assume the normal molybdenum content of soils in this area to be 1 ppm or lower. Winogradov<sup>13</sup> in a survey of all kinds of Russian soils, using a caustic soda attack, reports an average of 2.6 ppm with no horizon ever exceeding 4 ppm. The same author gives about 1 ppm as a general average for all other soil analyses reported elsewhere in the world. Some soils, for example in Holland, carry only 0.01 ppm molybdenum. In contrast, an alkaline soil overlying a sedimentary formation rich in molybdenum may contain much more of this metal than the parent rock. Amounts of more than 100 ppm molybdenum have been recorded in areas of England, where it causes a cattle sickness called *teart disease*. Any apparent molybdenum anomaly in soils must be interpreted with caution. Nevertheless, examinations of many porphyry coppers in western North America have usually shown the presence of comparatively high molybdenum anomalies in related soils, amounts of from 20 to 30 ppm being common. Furthermore, as molybdenum is more soluble than copper, a molybdenum halo tends to extend farther and to be more conspicuous against a low background than the more important copper with which it is associated. A preliminary search for a porphyry copper may well be expedited by using molybdenum as a pathfinder in a wider-spaced grid than would be practicable using copper.

## Conclusions

A survey of available literature and the writers' own fragmentary experience suggests that where the investigator is dealing with residual soils almost any orebody, or unusual concentration of an element or elements, will be reflected in the overlying soil. Where he is dealing with transported soils the anomalies involved are much weaker. Much more data and experience are needed before soil anomalies in drift-covered areas can be generally assessed and exploited as effectively as can biogeochemical anomalies. In each case the problem of selecting an appropriate technique is dependent on a correct assessment of the origin, the group, and the classification of the soil involved. In short, each problem must be considered on its own merits.

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# Flowsheets

## Types ——— Uses

by O. W. Walvoord

The contents and information contained within a flowsheet should naturally be determined by its purpose and use. A list of the more important items would include:

Path of ore stream.  
Equipment: description, number, and position.  
Tons per hour: dry solids.  
Gallons per minute: liquids.  
Gallons per minute: pulp, solids, and liquids.  
Gallons per minute: water added.  
Percent solids by weight.  
Size of materials.  
Reagents: amount and place of application.  
Sampling information.  
Assays of various products.  
Other metallurgical and mechanical data required.

Metallurgical information on a flowsheet should be included in the units or terms most likely to be needed. For example, "gallons per minute: pulp, solids, and liquids" is used to determine pump duty and pulp velocities in pipes.

**T**O those working in the mineral industry, the flowsheet is a familiar and valuable tool, seldom used, unfortunately, to its fullest advantage. As with so many other commonplace and simple items, there is little or no attempt to expand on the forms and types of flowsheets.

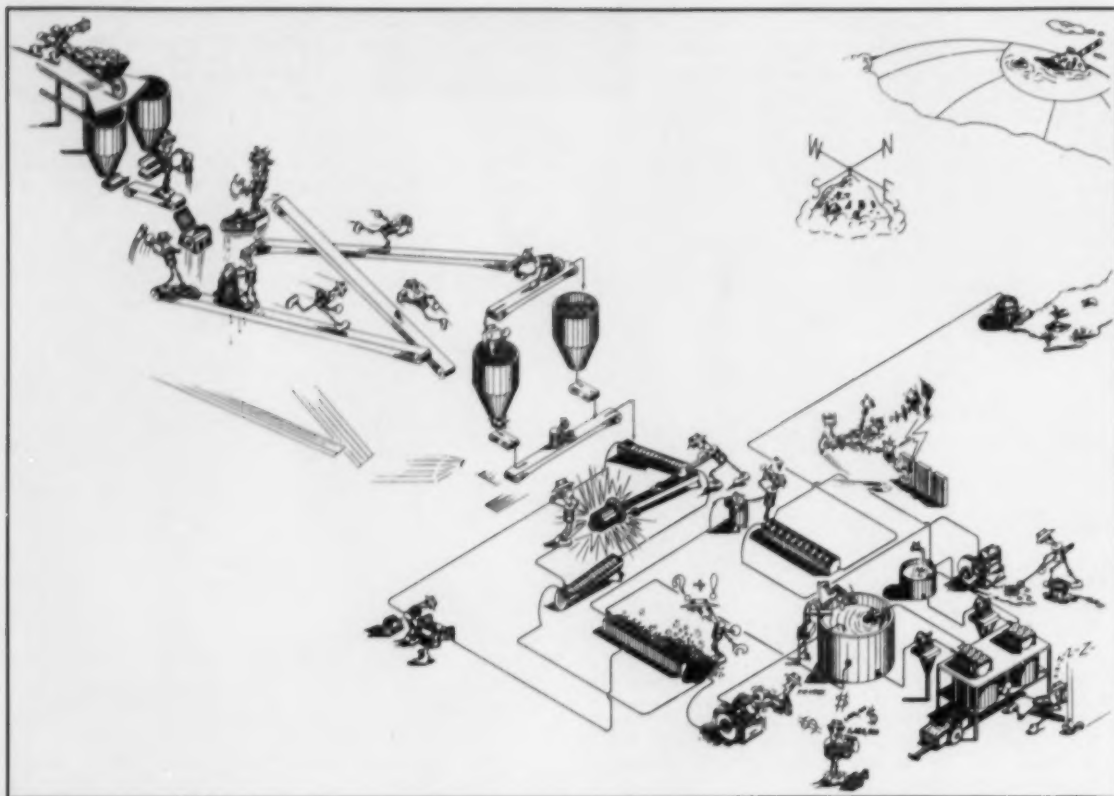
A flowsheet or flow diagram may be defined as an illustration showing circulation of the ore stream in a concentrating plant. It may be further described as an explanatory graphic design or picture.

A flowsheet is obtained by interpreting the metallurgists' research and ore test data, usually with some adjustments to suit the economies of the project. It brings together, in compact form, information from a number of sources.

Selection of the type of flowsheet naturally depends on its use, and thus a division can be made as to whether the use is technical, nontechnical, or both. No doubt the qualifications of the draftsman will influence the type chosen.

O. W. WALVOORD, owner, O. W. Walvoord Co., Denver, Colo.

USES → TYPES ↙	TECHNICAL				Nontechnical				
	METALLURGIST	SUP'T & OPERATORS	RESEARCH METALLURGIST	MILL CONTRACTOR & ENGR	OWNERS	MANAGERS	FINANCIAL	COST ACCOUNTING	PUBLIC RELATIONS
LINE	OK	OK	OK	OK	NG	NG	NG	NG	NG
BLOCK	OK	OK	OK	OK	OK	OK	NG	OK	NG
PICTURE WITH LEGEND	OK	OK	OK	OK	OK	OK	OK	OK	NG
PICTURE - COLORED	NG	NG	NG	NG	OK	OK	OK	OK	OK
CONDENSED - TAGGART	OK	NG	OK	NG	NG	NG	NG	NG	NG
PICTORIAL	OK	OK	OK	OK	OK	OK	OK	OK	OK



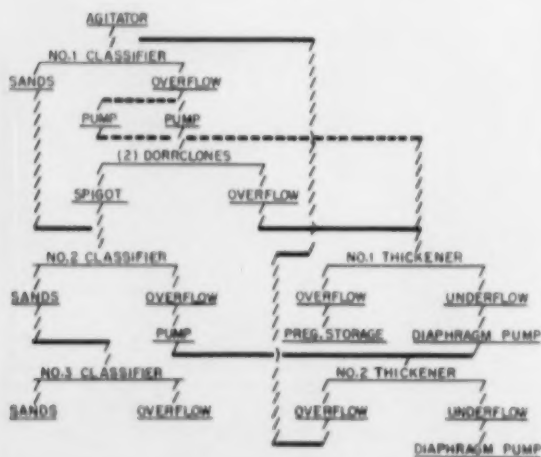
MBD-MILLMAN'S BAD DREAM

Considering the technical aspect, the metallurgist is the first to start interpreting the vast and varied amount of information contained in a research report. His interpretation is followed by consolidation, summary, and recommendation in the form of a flow diagram. This job of interpretation and assimilation can be well or poorly done, and the results of its use can be likewise, sometimes to the sorrow of many. Good judgment, achieved by years of

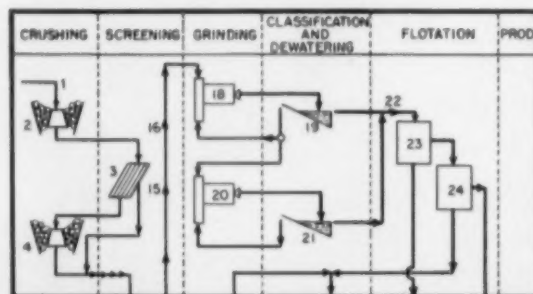
experience, is the best qualification for this work.

Mill superintendents and operators think and speak in terms of an illustrated flowsheet, even though one may not have been prepared. Usually during the life of a plant, material flow is periodically changed to improve the metallurgy, and in the more involved plants, better judgment can be exercised by first studying a printed flowsheet. New operators are more easily taught and costly errors

#### LINE TYPE



#### CONDENSED TYPE-TAGGART



#### LEGEND:

1. 20 AND 30 CU YD SIDE DUMP STD GAGE CARS FROM MINE.
2. 1 @ 48-IN. GYRATORY, 200 HP MOTOR, BELT DRIVE.
3. ETC.-----



Public relations may seem remote from the subject of flowsheets, but certain types of flow diagrams

To conclude, the type of flowsheet and its contents should be carefully chosen for specific purpose. No one type best fits all needs. Clarity and thoroughness of presenting the information is the ultimate goal.





# Modernization of Bunker Hill Presintering Practices

by Harold E. Lee and Donald Ingvaldstad



Charge storage and proportioning plant showing air conditioned tunnel in which the sinter charge is composited.

AT Bunker Hill the original charge storage and preparation system was installed in 1917 to accommodate lead-silver gravity mill products. Only minor tonnages of wet fines such as vanner and flotation concentrates were received. Charge flux and diluent requirements were provided by an ample supply of siderite middlings and coarse lime-rock. While oversize material was crushed through  $\frac{1}{4}$ -in., the use of roll crushers in series resulted in a more or less granular, free-running charge of adequate porosity. Under such conditions, receipts could be proportioned directly from receiving bins, and suitable blending was obtained by passing the resultant layered composite through a small Stedman disintegrator.

This elementary system served well for production and smelting of an extremely lead-rich sinter, in the low column blast furnace. Here sinter physical quality is less critical, and appreciable quantities of raw flux and oxidized ore may be charged directly to the blast furnace without seriously impairing furnace capacity.

Prior to 1938 the relative proportions of zinc receipts were low and extraneous flux requirements at a minimum. However, subsequent war-inflated zinc demands brought marked increase in fine concentrate and slimy zinc leach residue receipts and an abrupt introduction to smelting a more refractory zinciferous charge. The higher temperature demands of the more refractory zinciferous charge required a higher smelting column and the higher column, in turn, rendered the blast furnace less receptive to improperly prepared feed. Inadequate presinter processing facilities prevented the production of acceptable sinter, and blast furnace production declined to 50 pct of former capacity.

In view of a prevailing contention among lead metallurgists as to the deleterious action of high zinc slag on blast furnace capacity, it was natural to overstress this factor and to concentrate on possible changes in furnace design. Another interpretation was that primary correction should be sought through expanded sintering facilities. This divergence of opinion, together with the extreme material shortages of the 1940's, delayed corrective

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Table I. Comparative Lead Blast Smelting Data

Plant and Conditions	Slag Type		Charge, Tons per Day*	f (FeO CaO ZnO)	FeO: CaO Ratio	Acidity Data		Relative Acidity
	Ingredient	Pct				Metal- Oxide	Oxygen	
Plant A Tuyere area, 48x100 in. Column 18 ft, blast 46 oz Charge Pb content: 22 pct	SiO <sub>2</sub>	23.1	635	66.3	1.4	SiO <sub>2</sub>	12.31	0.44
	FeO	30.1				FeO	6.71	
	CaO	21.8				CaO	6.21	
	ZnO	14.4				ZnO	2.84	
	RO	10.6				e	28.07	
Plant B Tuyere area, 48x180 in. Column 18 ft, blast 40 oz Charge Pb content: 36 pct	SiO <sub>2</sub>	22.5	625	66.4	1.8	SiO <sub>2</sub>	12.53	0.44
	FeO	37.5				FeO	8.36	
	CaO	20.5				CaO	8.84	
	ZnO	8.4				ZnO	1.65	
	RO	10.1				e	28.38	
Plant C-1 Tuyere area, 52x180 in. Column 14 ft, blast 45 oz Charge Pb content: 38 pct	SiO <sub>2</sub>	29.8	450	60.1	1.8	SiO <sub>2</sub>	15.88	0.52
	FeO	31.5				FeO	7.02	
	CaO	20.2				CaO	8.78	
	ZnO	8.4				ZnO	1.65	
	RO	10.1				e	30.31	
Plant C-2 Tuyere area, 52x180 in. Column 18 ft, blast 47 oz Charge Pb content: 30 pct	SiO <sub>2</sub>	22.5	587	65.4	1.9	SiO <sub>2</sub>	11.99	0.44
	FeO	31.9				FeO	7.11	
	CaO	16.3				CaO	4.65	
	ZnO	17.2				ZnO	3.39	
	RO	12.1				e	27.14	
Plant C-3 Tuyere area, 52x180 in. Column 14 ft, blast 47 oz Charge lead content: ?	SiO <sub>2</sub>	31.6	555	65.5	2.0	SiO <sub>2</sub>	11.51	0.43
	FeO	29.4				FeO	6.56	
	CaO	14.7				CaO	4.19	
	ZnO	21.4				ZnO	4.27	
	RO	12.9				e	26.53	
Plant D Tuyere area, 48x180 + in. Column 18 ft, blast 39 oz Charge lead content: 25.4 pct	SiO <sub>2</sub>	26.4	284	60.1	1.3	SiO <sub>2</sub>	14.07	0.49
	FeO	30.2				FeO	6.73	
	CaO	22.4				CaO	6.38	
	ZnO	7.5				ZnO	1.48	
	RO	13.5				e	28.66	
Plant D-1 Tuyere area, 48x180 + in. Column 18 ft, blast 42 oz Charge lead content: 21.5 pct	SiO <sub>2</sub>	25.8	317	61.5	1.4	SiO <sub>2</sub>	13.75	0.48
	FeO	30.5				FeO	6.85	
	CaO	21.6				CaO	6.18	
	ZnO	9.4				ZnO	1.85	
	RO	12.7				e	28.61	
Plant E Tuyere area, 48x180 in. Column 13 ft, blast 36 oz Charge lead content: 37 pct	SiO <sub>2</sub>	19.5	300	67.3	4.6	SiO <sub>2</sub>	10.39	0.41
	FeO	27.8				FeO	8.43	
	CaO	8.2				CaO	2.34	
	ZnO	21.3				ZnO	4.20	
	RO	13.2				e	25.36	
Bunker Hill smelter, September 1937	SiO <sub>2</sub>	22.5	609	67.1	2.4	SiO <sub>2</sub>	11.99	0.44
	FeO	36.0				FeO	8.03	
	CaO	15.1				CaO	4.30	
	ZnO	16.0				ZnO	3.15	
	RO	10.4				e	27.47	
Bunker Hill smelter, August 1940	SiO <sub>2</sub>	25.2	379	58.6	2.3	SiO <sub>2</sub>	13.43	0.50
	FeO	36.3				FeO	6.76	
	CaO	13.0				CaO	2.71	
	ZnO	16.3				ZnO	3.21	
	RO	15.2				e	27.11	

\* Monthly or longer period averages.

procedure. During this period, however, operational data from many sources were assembled and analyzed.

Table I is a comparative summary extracted from this smelting data. It will be seen from this table that slag zinc content alone is not critical, but the type of slag in other respects is indicated to be of primary importance in controlling blast furnace capacity. In fact, assuming the charge to be predominantly sinter of proper FeO:CaO ratio<sup>1</sup> and containing minor residual (RO) compounds ranging from 10 to 12 pct (thus the balance silica) a simple rule for attaining high blast furnace capacity appears to demand a slag in which the % of FeO + CaO + ZnO approaches 66 pct. This rule presupposes that all slag forming ingredients and proper sulfur diluents exist intimately incorporated in the sinter plant feed and that the composite presinter charge has been endowed with adequate porosity. Under such conditions, fast smelting sinter will follow.

In the period 1948-1949, extensive laboratory experiments were conducted not only to determine related overall smelting requirements, but also to select the most promising alternative procedures. After all conclusions drawn were checked by actual pilot plant operations, 1949-1950, chemical and physical presinter charge control was proved to be mandatory.

To attain such control at a custom smelter subject to long periods of adverse weather and dependent on coarse flux and a wide variety of ore receipts necessitated:

- 1) An all-weather system.
- 2) Facilities for crushing all oversize materials to  $\frac{1}{4}$ -in.
- 3) Enough bins—designed to permit positive flow—to maintain adequate segregation of charge ingredients.
- 4) Provisions to obtain presinter analysis of the composite charge and a means of correcting indicated deficiencies.
- 5) Adequate charge blending and pelletizing facilities.

It was not economically feasible to realize the foregoing requirements by renovating the existing system, and construction of a new plant was decided upon. This new plant, designed and constructed under contract by Stearns-Roger Mfg. Co., is comprised of four distinct units: a crushing plant; a storage, proportioning, and blending plant; a bedding plant; and a pelletizing plant. Construction was started in the fall of 1951 and completed in October 1953. The initial crushing plant unit was finished and placed in operation in September 1952.

**Crushing Plant:** The crushing plant was molded into limited space of not too desirable contour. As shown in Fig. 1, it is designed for flexible, multi-

purpose service. It is utilized for: 1) crushing and grinding, to  $-\frac{1}{4}$ -in., minor volumes of crude ores and major tonnages of charge diluents, fluxes, and circulating byproducts; 2) intermediate reduction and sizing of both finished byproducts and pallet dressing which is required for one-pass sintering. As far as dry crushing is concerned, the design is unique in employing a rod mill and including a dryer in the circuit. It will be noted that provisions are made for bypassing both dryer and rod mill and for delivery of products to variable destinations.

Crushing plant feed is received through ten railroad bins of 2600-cu ft capacity, one of which feeds direct to the dryer for the processing of wet slimy materials not amenable to passage through the more devious coarse crushing system. The remaining nine bins feed through chutes with arc gates onto a mobile apron feeder which regulates the flow via belt conveyor to the coarse crushing section.

Primary crushing is accomplished in a Traylor 30x36-in. type H jaw crusher. However, the feed opening of this unit is restricted to 24x36 in. to accommodate tough furnace products such as matte and speiss. Jaw motion is  $\frac{3}{4}$  in. and a minimum open setting of  $2\frac{1}{2}$  in. is used.

The  $-\frac{1}{2}$ -in. jaw crusher discharge is delivered to an Allis-Chalmers No. 648 Hydrocone crusher, which operates in open circuit with a 4x8-ft ( $\frac{1}{2}$ -in. openings) ac rod deck screen. The  $-\frac{3}{4}$ -in. product of this secondary crushing circuit is conveyed to a Jeffrey continuous bucket elevator 77 ft high, the discharge of which (sampled if desired by a Geary-Jennings sampler) can be diverted to multiple destinations by means of a three-way splitter utilized in conjunction with two reversible belt conveyors:

- 1) One of the above splitter legs delivers  $-\frac{3}{4}$ -in. sinter to a 4x8-ft Nordberg Symons rod deck screen with  $\frac{1}{4}$ -in. openings. Oversize is returned to the sinter plant for pallet dressing and undersize is belt conveyed to storage in the proportioning plant for use as a sulfur diluent.

- 2) A second splitter leg, via reversible conveyor, is employed to bypass the rod mill completely (either to the proportioning mill or to railroad cars) and to deliver material of excessive moisture content to an 8x60-ft Stearns-Rogers oil-fired rotary dryer before it goes to the rod mill. This dryer operates on a  $\frac{1}{4}$ -in. per ft slope and is driven at 4.45 rpm by a 75-hp motor. The vented dryer gas is cleaned in a No. 24 type N Rotoclone equipped with an Esperanza-type slime remover. The slime is dewatered for circulation along with similar plant products and the clean gas exhausted through a 3-ft diam steel stack by means of a No. 80 Norblo fan. The dryer discharge, by means of a heat-resistant conveyor system, may bypass the rod mill or be delivered to it.

- 3) The predominant flow of rod mill feed passes through the third splitter leg to a reversible conveyor which feeds either of two steel bins, 12 ft O.D. by 17 ft high. From these surge bins the rod mill flow is regulated by variable speed feeders.

Because predesign tests demonstrated its efficient open circuit delivery of a  $-\frac{1}{4}$ -in. product from a range of feed types containing up to 2 or 3 pct moisture, rod milling was selected in preference to the usual closed circuit roll crushing. A 9x12-ft Allis-Chalmers peripheral discharge dry rod mill is employed. This mill is fed by an 18-in. diam, 70-rpm, 5-hp screw feeder and is driven at 17.2 rpm by a 450-hp synchronous motor. Lorain liners  $2\frac{1}{2}$  in.

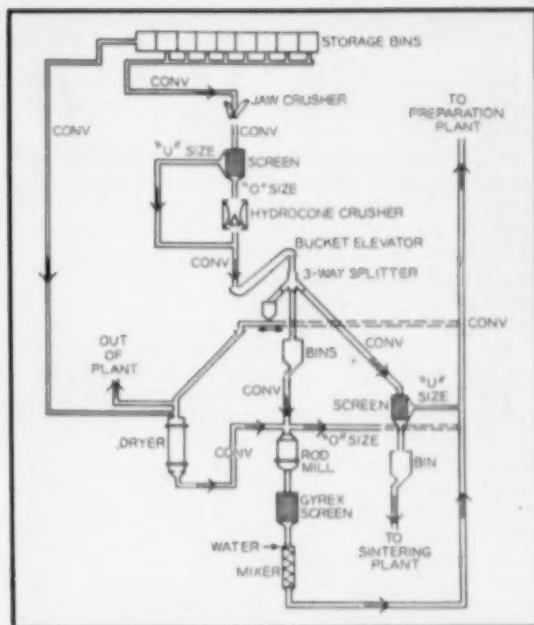


Fig. 1—Crushing building at the Bunker Hill Co. charge preparation plant.

thick are employed and a 25 to 30-ton rod load is maintained by the periodic addition of  $3\frac{1}{2}$ -in. rods.

Dry rod mill performance to date has been very satisfactory. After three years of operation, the original liners are still in service and the lifters have only recently been replaced. About once a month, broken rods are removed and 15 to 20 new rods added. Table II presents feed and discharge sizes when the rod mill is operating on two different types of feed at a capacity of about 60 tph.

The rod mill discharge passes successively to a 36x54-in. Robins Gyrex screen (1 mesh) for scalping out broken rods and a Jeffrey double paddle mixer (12 ft long by 3 ft 11 in. wide) for wetting to prevent excessive dusting before it is belt conveyed to the proportioning plant.

All conveyors are interlocked and a dust collection system serves transfer points as well as crushing and screening equipment. The dust-laden air is filtered through an Aeroturn dust collector containing 24 wool felt bags, 18-in. diam by 18 ft long. A size 80 Norblo exhaust fan driven at 800 rpm by a 60-hp motor vents 25,000 cfm through this unit.

As already indicated, this plant reduces a wide variety of products. For operation on large tonnage, including flux and diluent requirements (limerock, slag, and sinter), an average rate of 55 tph is maintained. For processing smaller tonnages of variable

Table II. Dry Rod Mill Grinding Performance

Mesh	Feed, Pct <sup>a</sup>	Discharge, Pct <sup>a</sup>	Feed, Pct <sup>b</sup>	Discharge, Pct <sup>b</sup>
+2	80.9	0.0	69.1	0.0
+4	30.0	0.8	15.3	0.8
+8	10.1	15.7	5.9	9.0
+14	4.0	24.5	3.2	21.0
+28	1.8	18.7	1.6	16.5
+100	1.6	22.0	2.0	17.5
+200	0.3	6.5	0.5	8.3
-200	1.2	11.5	2.2	26.6

<sup>a</sup>  $-\frac{3}{4}$ -in. dump slag at 61.3 tph; rod load 30 tons.

<sup>b</sup>  $-\frac{3}{4}$ -in. limerock at 57.3 tph; rod load 30 tons.

circulating byproducts, average capacity is obviously reduced by time lost in switching from one material to another. Depending on tonnage, two to three shifts per day are required with a three-man operating crew. One extra clean-up man is employed on day shift.

**Charge Storage and Proportioning Section:** Immediately south of the new plant, adjacent to the railroad bins already mentioned, 17 additional bins receive fine concentrate and leach residue shipments. Starting with these receiving bins and picking up the crushing plant load from the east, Fig. 2 traces the material flow through the storage and proportioning section.

A 64x288-ft building houses this section. Along the east wall are 11 concrete bins for storage of crushed fluxes, diluents, and circulating byproducts. Five of these bins are of 7000-cu ft capacity and six of 3500-cu ft capacity. Eight 7000-cu ft bins along the opposite western wall store fine receipts which bypass the crushing plant. Parallel between these bordering storage bins are 19 steel proportioning hoppers of 1000-cu ft capacity. Material transfer from storage to the hoppers is accomplished with a 2-yd Blaw Knox clamshell bucket operated from a P&H overhead crane with 61-ft span. The hoppers are spanned by a steel rail grizzly system which is utilized for bucket cleaning and for breaking compacted lumps. The grizzly rail spacing varies from 6 to 18 in., depending on the character of the material being handled.

The segregation of incoming flux, diluents, and circulating byproducts is obvious. According to the type of slag-forming ingredients they contain, incoming ores are segregated into five classifications. Variations in composition of materials drawn from storage are minimized by provision of adequate bin capacity and by the practice of bedding the flow into storage. Incoming flow is diverted to its proper storage bin by a Robins motor-actuated wing tripper. A selector switch is used to locate the tripper, and bedding of the discharge is effected by an oscillating tripper movement between limit switches.

In an air-conditioned tunnel beneath the central proportioning hoppers, a composite charge is formed by controlled mechanical discharge of the 19 products contained. One of these bins, utilized for very low feed rates, is screw discharged. All other bins employ 4x8-ft pan feeders, of which six are ratchet driven and 12 have a variable speed continuous drive. Feed rates are controlled by adjustments of both gate openings and pan speeds. Gobbing of the pan discharge onto the collection belt is minimized by use of a hinge-mounted solid flight screw, which contacts and cuts the face of the discharge ribbon.

All proportioning hoppers discharge onto a 30-in. gathering conveyor that spills to a cross-belt for delivery to a Pennsylvania, size CF-7-38, reversible impactor driven at 800 rpm by a 200-hp motor. Overall flow rate is limited by the impactor capacity of about 200 tph. In view of this limitation, ores are proportioned on the basis of receipts, circulating byproducts in accordance with production rates, and fluxes and diluents on the basis of metallurgical requirements. Between 5 and 10 pct of estimated flux and diluent requirements is purposely withheld at this stage to facilitate control in subsequent charge correction operations.

In passage through the impactor, ingredient lumps are broken and very effective blending is accomplished. The blended flow is conveyed over a Mer-

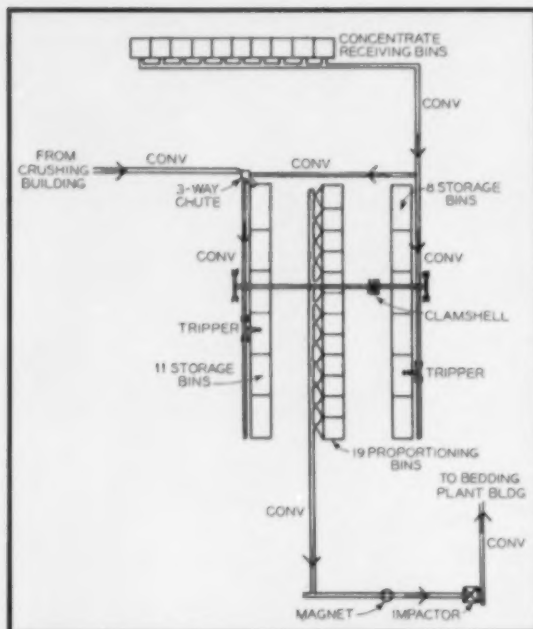


Fig. 2—Preparation building at the Bunker Hill Co. charge preparation plant.

rick Model E Weightometer and Rateograph, thence to a two-stage bucket-type sampler before being diverted to the bedding plant.

Three operators and one clean-up man, working one shift per day, composite, blend, and correct the 24-hr requirement of 1500 tons. The three operators, all crane men, rotate between the crane, feeder floor, and conveyor stations. The use of small, separate, free-flowing proportioning hoppers originated in Port Pirie practice and was later adopted by the American Smelting & Refining Co. plant at Helena, Mont. It is very effective in obtaining low-cost positive movement of sticky concentrate and slimy residue receipts. Materials compacted in storage are broken and fluffed during transfer from storage to the proportioning hoppers. These hoppers are shallow enough to minimize further packing and the feeders are wide enough to discourage arching.

**Bedding Section:** In addition to providing a desirable weatherized storage of blended charge, the bedding section is the key to positive metallurgical control. As outlined above, the composite flow is weighed and sampled before being bedded. On the basis of known weight and analysis, each bed is metallurgically corrected, before reclaiming, to target sintering and blast furnace requirements.

The 64x192-ft bedding section floor area accommodates four 925-ton bedding piles. As may be seen from Fig. 3, this area is divided longitudinally by a collection conveyor that operates sublevel in a central trench. Beds are laid around this trench, counter clockwise, by means of overhead trippers operating from belts that span each side of the building. The trippers are spotted by selector switches and oscillate over the bed length between limit switches.

As was mentioned previously, the bedding and correction of 24-hr sinter plant requirements is completed in a single 8-hr shift. Normally, one bed is being laid while a second is delayed awaiting assay. A third bed is either ready for, or in the process of, metallurgical correction (accomplished



usually at the start or close of a shift, by the proportioning plant crew over the regular belt system), and the fourth bed is being reclaimed.

Bedding piles are reclaimed at a rate of 175 to 200 tph and the operation is practically automatic. The reclaimer is interlocked with a pressure switch that stops the unit when the pelletizer surge bin is full. As a safety measure, starting is manual. The reclaimer, of Stearns-Roger—Bunker Hill design, operates counter clockwise in an orbit about the collection trench from overhead rails. This unit consists of a mobile, triangular, multitoothed, reciprocating harrow coupled to a drag conveyor. It eats into and excavates the beds at right angles to their formation. The reciprocating harrow, set at the angle of slope, continuously loosens material on the face which slides into the drag conveyor and is carried into the collection trench. Forward motion of the reclaimer is automatic and intermittent, being controlled through a switch actuated by a feeler located just above the drag.

Reclaimed material is delivered by the collection conveyor to a surge bin at the head of the pelletizing section. Pelletizing, and thus obviously reclaiming, is on a two-shift basis. One part-time man per shift is required.

**Pelletizing Section:** In the pelletizing section the sinter charge is endowed with porosity. This desirable physical conditioning in preparation for sintering, though successfully employed in zinc operations, has long been neglected by lead metallurgists. As indicated by Fig. 4, the reclaimed, corrected charge is fed from a 100-ton surge bin by a 4x10-ft Jeffrey feeder into the pelletizing circuit. Pelletizing is usually accomplished (two-shift basis) with a two-man crew at the rate of 110 to 120 tph—the reclaimer operator aids in this operation.

Feed flow is initially conditioned with water in a 5x9-ft A.O.R. pugmill rotating at 6.5 rpm. Moisture addition is controlled manually from an observation point at the subsequent pelletizer drum discharge. Here a flowmeter is provided for re-establishing conditions after shutdowns.

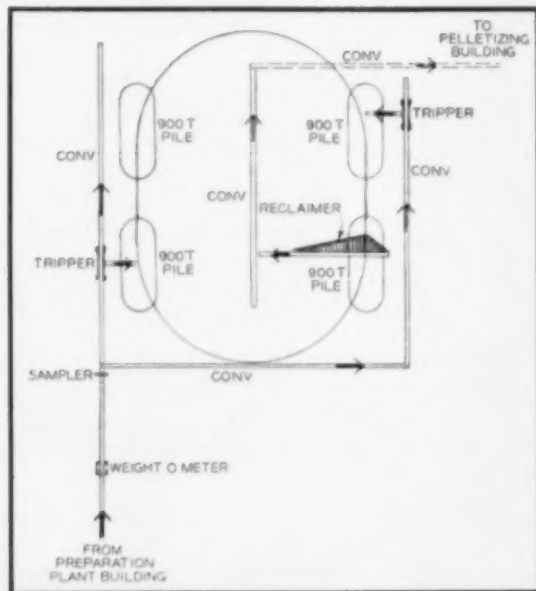


Fig. 3—Bedding plant building at the Bunker Hill Co. charge preparation plant.

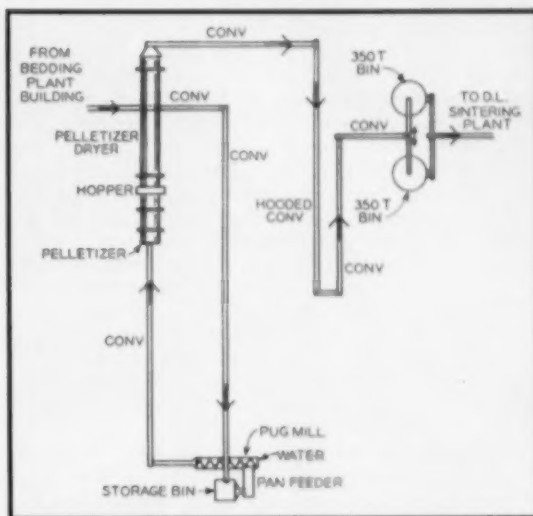


Fig. 4—Pelletizing building at Bunker Hill Co. charge preparation plant.

Flow from the pugmill is advanced to a 8x15-ft rotary pelletizer, which operates at 9 rpm and a slope of 4 in. over its 15-ft length. Build-up on the drum surface is limited to about 2 in. by a rotary cleaner consisting of a pipe shaft into which short steel cutting rods have been threaded.

As might be suspected, the moisture content required to initiate agglomeration varies with charge character. Charges containing higher proportions of fines accept more moisture and are less critical in control than more granular charges. Below a certain moisture content, agglomeration is ineffective; too much moisture results in oversize nodules not acceptable for one-pass sintering. As seen from the following typical pellet sizing data, an attempt is made to limit the maximum pellet size to ¼ in.

Mesh	Wt, Pct
+4	9.1
+10	38.5
+20	31.7
+35	12.5
-35	8.2

From the pelletizing drum, the charge drops through a chute into a 7x30-ft Stearns-Roger rotary dryer, which operates at 11.3 rpm on a slope of ¾ in. per ft. No lifters are used other than six ½-in. angle bars welded to the shell. The purpose of the dryer is to surface-harden the pellets. Very little actual drying is sought, only 1 to 1.5 pct moisture being removed.

The finished surface-set pellets leaving the dryer are conveyed via a partially hooded belt system to one of two sinter plant surge bins.

A marked increase in smelting capacity attended the start of the new preparation plant operations and the charge uniformity and control provided has enabled consistent maintenance of all subsequent operations at their highest capacity levels.

#### Reference

<sup>1</sup> H. O. Hofman: Metallurgy of Lead, pp. 307-311. First edition, 1918.

Discussion of this paper (2 copies) sent to AIME before Dec. 1, 1956, will appear in AIME Transactions, Vols. 306 and 309, and in JOURNAL OF METALS, October 1957, and MINING ENGINEERING.

# Preconcentration of Primary Uranium Ores by Flotation

by Burt C. Mariacher

**E**XTRACTION of uranium from ores is being accomplished by processes which, for the most part, subject the entire ore to acid or carbonate leaching. Ore deposits with a  $U_3O_8$  content below 0.10 pct  $U_3O_8$  are seldom considered suitable for treatment by leaching.

A preliminary concentration that would enrich the uranium content of an ore by a simple, low cost process based on physical properties of the ore might result in some low grade deposits becoming commercial ores. In addition, the process might be employed in existing operations to reduce transportation and leaching costs and to increase capacity of existing leaching plants.

A study to attempt the development of a preliminary concentration process for primary uranium ores was undertaken by the Colorado School of Mines Research Foundation under sponsorship of the U.S. Atomic Energy Commission. The objective of this work was to produce concentrates containing 0.25 pct  $U_3O_8$  from the low grade ores tested.

**Ores Tested:** The main effort was devoted to the low grade primary uranium ores from northwestern Saskatchewan. Samples were obtained from the Beaverlodge operation of the Eldorado Mining & Refining Ltd. Additional primary ores, obtained from deposits in Gilpin County, Colo., contained from 0.07 to 0.10 pct  $U_3O_8$ .

**Summary of Concentration Tests:** The Beaverlodge ore was tested to determine amenability of the ore to concentration by magnetic, electrostatic, gravity, and scrubbing processes. None of these produced satisfactory results. Both gravity and magnetic processes produced fairly good concentrates when closely sized fractions of the ore were treated, but on the basis of treating the total ore, recovery was poor. Preparation of sized fractions and the low capacity of equipment for suitable concentration made these methods impractical.

As flotation offered the advantage of treating the total ore without intermediate sizing, the main effort was in this direction. A flotation process was developed that fulfilled the concentration objectives as set by the AEC. Pilot plant testing was used to verify results obtained from laboratory batch testing.

**Mineralogy:** A petrographic examination of the Beaverlodge ore included a study of polished sur-

faces and identification of the radioactive mineral by autoradiograph and X-ray diffraction. Approximate quantitative mineral identification was as follows: quartz, 60 pct; orthoclase feldspar, 20 pct; chlorite, 10 pct; carbonates, 5 pct; and miscellaneous minerals, 5 pct. Included in this last group were plagioclase feldspar, pyrite, mica, chalcopyrite, pyroxene, sericite, magnetite, galena, and uraninite.

The most general occurrence of uraninite was in the form of crusts and thin coatings on limonite-stained grains of pyrite, quartz, and pyrite-quartz intergrowth. At least 90 pct of the uraninite was still attached to other minerals in a 100 by 200-mesh size fraction. The uraninite crusts were as small as 10 to 20  $\mu$  diam, and 5 to 10  $\mu$  thick.

## The Flotation Process

Petrographic examinations of the Beaverlodge ore had indicated the impracticability of attempting to concentrate the uranium by floating individual grains of uraninite. Liberation of the uraninite required grinding to sizes below those suitable for flotation. However, there was preferential association of the uraninite with some minerals while others were free of uraninite attachment. The approach to the development of a flotation process was, therefore, based upon an attempt to concentrate the uraninite by floating carrier minerals. The following paragraphs discuss the various stages of the process with regard to the factors tested and the conditions under which best results were obtained.

**Grinding:** The most effective size range for flotation was  $-150$  mesh  $+13 \mu$ . The  $-13 \mu$  material in the final concentrate had a higher  $U_3O_8$  content than the total ore, but not as high as the average concentrate; however, rejection of slimes before flotation was prohibitive because of the loss in uranium carried in the  $-13 \mu$  fraction. Grinding techniques which contributed to a minimum production of fines, such as stage grinding, were then employed.

**Quartz and Silicate Depression:** These minerals represented approximately 80 pct of the ore and were free to a large degree of uraninite attachment. Significant improvement in the grade of the concentrate was obtained by depression of these minerals with hydrofluoric acid or sodium fluoride.

**Promoter:** Selective stage flotation of uraninite carrier minerals was simplified by development of a single promoter mixture. The mixture consisted of an emulsion of a fatty acid, fuel oil, and a petroleum sulfonate and was selected after a comprehensive series of tests. It contained three parts by weight of an oleic and linoleic acid such as Emersol 300,

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three parts by weight of No. 2 fuel oil, and one part by weight of a petroleum sulfonate such as Oronite L. The mixture was emulsified in water at 20 to 25 pct reagent strength.

**Rougher Flotation:** The reagents and technique employed in the rougher flotation were primarily directed toward maximum recovery. The amount of promoter mixture required for acceptable recovery varied with the type of ore and ranged from 10 to 20 lb of active promoter mixture per ton of ore. Stage addition of the promoter improved recovery. Sulfuric acid was used to maintain a pH of 6.0 during flotation. A lower pH resulted in improved concentrate grade, but was not suitable because of a lower  $U_3O_8$  recovery.

**Concentrate Cleaning:** The rougher concentrate was cleaned without additional reagents other than sulfuric acid for the regulation of pH. By variation in the pulp density and number of flotation cleaning steps, it was possible to select the grade of concentrate desired between 0.22 and 0.28 pct  $U_3O_8$ , with corresponding recoveries of 85 and 78 pct of the  $U_3O_8$ .

**Reagent Additives:** The promoter mixture had strong collecting properties and tended to float the slimes *en masse* in a voluminous, tough froth. Some degree of success was obtained in modifying the froth properties by adding Ucon 75-H-1400, a synthetic lubricant, to the promoter emulsion in the amount of one part to ten parts of active promoter mixture. Although a sodium ligno-sulfonate type of dispersant such as Marasperse CB was found to improve the grade of the concentrate, it lowered recovery.

#### Pilot Plant Operation

A pilot plant test was conducted to evaluate the process under continuous operation. The plant was equipped for a feed rate of about 40 lb per hr. The grinding circuit consisted of a ball mill in closed circuit with a classifier. Rougher and cleaner flotation machines each consisted of a 6-cell unit of Denver Sub-A, No. 5 cells.

The rougher concentrate was the combined float products from the six rougher cells operating in series. Stage addition of promoter was accomplished by a primary addition in a separate conditioner preceding flotation and subsequent addition to intermediate cells in the series.

Cleaner cells were operated with a counterflow of tailings and concentrate with progressive cleaning of the float product. The cleaner tailing was returned to conditioning ahead of rougher flotation. Table I presents data typical of the metallurgical results obtained by the process in the pilot plant test treating the Beaverlodge ore.

The close association between uraninite, limonite, and quartz presents a major problem in the flotation process. Presumably, further depression of quartz would result in a substantial loss in recovery of uraninite because of the limonite-quartz-uraninite intergrowths. Conversely, higher uraninite recovery could only be obtained by sacrifices in grade of concentrate and ratio of concentration.

Table I. Pilot Plant Flotation Data

Heads	$U_3O_8$ , Pct Cleaner Concentrate	Rougher Tailing	$U_3O_8$ , Recovery, Pct	Ratio of Con- centration
0.096	0.219	0.023	85.0	2.7 to 1
0.099	0.288	0.030	77.8	3.7 to 1
0.103	0.235	0.026	84.6	2.6 to 1

#### Colorado Ores

Only cursory petrographic studies were made of the Colorado ores. The Highlander ore was essentially pink microcline and quartz with pyrite coating. Other minerals in significant quantity were orthoclase, muscovite, biotite, plagioclase, chlorite, and pyrite. The uranium mineral was too disseminated for detailed study but was assumed to be pitchblende. The Carroll ore was essentially an altered, kaolinized silicious vein material with pyrite crystals, sphalerite stringers, and occasional cleavages of galena. Other minerals in significant quantity were illite, quartz, microcline, orthoclase, plagioclase, muscovite, and apatite. Stringers of soft pitchblende, averaging about 30  $\mu$  wide, were detected in a groundmass of quartzose material.

The flotation process developed for the Beaverlodge ore was employed for tests on these Colorado ores. They were not tested in the pilot plant, but batch tests produced more effective concentration than was obtained from the Beaverlodge ore.

The  $U_3O_8$  content of the rougher concentrate was within the objective of the work. Significant improvement in the grade of the concentrate was obtained in the cleaner flotation, but without pilot plant testing it was not possible to determine definitely the effect of the recirculated cleaner tailing. An assumption that the cleaner concentrate and rougher tailing obtained in batch tests could be maintained in continuous operation was reasonable because of the experience with the Beaverlodge ore.

Typical batch test results are given in Table II.

Table II. Representative Batch Test Results

Material	Highlander		Carroll	
	$U_3O_8$ , Pct	Distribution, Pct	$U_3O_8$ , Pct	Distribution, Pct
Feed	0.096	100.0	0.078	100.0
Rougher concentrate	0.274	81.3	0.219	78.3
Rougher tailing	0.025	18.7	0.026	24.7
Cleaner concentrate	0.570	86.8	0.338	61.5
Cleaner tailing	0.124	24.5	0.065	13.8

#### Conclusions

The conclusions which can be drawn from this investigation are as follows:

- 1) Preconcentration by flotation was effective in three out of four ores tested and its use should be considered in processing primary uranium ores.
- 2) In the case of ores containing finely disseminated uraninite, significant concentration may still be obtained by employing flotation of carrier minerals.
- 3) Evaluation of the benefits from preconcentration for an individual ore can be made by comparatively simple pilot plant operation.

#### Acknowledgment

The work reported here represents a combined effort by the engineering staff of the Colorado School of Mines Research Foundation. Significant contributions were made by F. T. Davis, B. H. Irwin, C. C. Martin, R. C. Merritt, and A. E. Meyer.

The Research Foundation wishes to express its appreciation to the Atomic Energy Commission for permission to publish the results of the testwork.

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# Flotation of Secondary Uranium Minerals

by John N. Butler and Robert J. Morris

A series of organic collectors has been developed which successfully float synthetic secondary uranium minerals, such as autunite, carnotite, and torbernite. Recoveries up to 97 pct have been obtained. With cleaning of rougher concentrates, ratios of concentration as high as 15:1 are possible on head assays of 0.10 to 0.50 pct  $U_3O_8$ . Additions of certain base metal salts aid in recovery and materially increase the rate of flotation and selectivity of the collectors for the synthetic minerals. Flotation tests on natural uranium minerals have not yet equaled results obtained on the synthetics, although these collectors do give better results than conventional collectors for nonsulfide minerals.

**R**APID increase in mining and milling uranium ores during the past seven years and the discovery of large tonnages of uranium-bearing material too low in grade to stand the cost of leaching have developed considerable interest in possible methods for beneficiating these marginal ores. Such ores are generally classed as those containing less than 0.10 pct  $U_3O_8$ . Development of a beneficiation method that would give both high recovery and high ratio of concentration would also make possible the beneficiation of higher grade ores and would provide higher grades of feed to existing leaching plants.

Although considerable research and testing on physical or physico-chemical beneficiation of domestic uranium ores has been done in the past, to the best knowledge of the authors only a single application of physical beneficiation is now in operation on a commercial scale. Flotation has been attempted on the basis of mineral association rather than by direct concentration of the contained uranium minerals. Flotation studies conducted on this project on certain ores gave recoveries of 60 to 70 pct of the uranium by the use of conventional flotation agents such as oleic acid, but ratios of concentration were in the order of 1.5:1 to 2.5:1. Subsequent cleaning to upgrade the concentrates rapidly increased losses in the cleaner tailings, which were not later refloated in the rougher flotation.

**Selection of Collector:** In selecting desirable organic collectors for these oxide systems, a thorough study was made of the relationship between structural characteristics and collector activity by an examination of the behavior of a number of different functional arrangements present in a variety of organic molecules, (see Fig. 1). It is generally accepted that a collector must have a relatively long-chain hydrocarbon radical and a chemically reactive electrophilic center. Such a requirement could be met

by a large number of compounds, but steric effects at the uranium mineral surface, solubility, compatibility with aqueous systems, air avidity, bond strength at the mineral surface, interfacial concentration of the collector, and diffusion rate of the formed complex from the air-water interface eliminated many as unsuitable for this purpose.

Preliminary investigations were completed of possible collector designs consisting of aliphatic and aromatic hydrocarbon radicals attached to stable combinations of nitrogen, oxygen, sulfur, and halogen electrophilic centers, Fig. 1. Tests were made to determine melting point spans, solubility of mineral-collector combinations in various solvents, reactions with soluble uranium salts, contact angles, and floatability by semi-quantitative beaker methods.<sup>1</sup> Contact angle determinations were not too useful because of the fine particle sizes of available mineral samples.

From the foregoing study it appeared that nitrogen-sulfur electrophilic centers coupled with straight-chain saturated alkyl hydrocarbon radicals would hold the most promise for floating secondary uranium minerals. As the dithiocarbamate compounds can be made to combine these attributes they were selected for further study.

The dithiocarbamates form a parallel structure to the xanthates, with the fortuitous exchange of



Fig. 1—Examples of structural types of functional groups examined.

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a nitrogen center for the oxygen molecule. This provided the required nitrogen-sulfur center for this application. The carbamates have been known for a number of years, particularly in the rubber industry.<sup>3</sup> The dialkyl dithiocarbamates are known to form colored complexes with metallic ions such as nickel, iron, and uranium. Uranium in both  $U^{IV}$  and  $UO_2^{++}$  states forms colored complexes with these molecules.<sup>2</sup> The dialkyl dithiocarbamates have been tried in a limited way as flotation reagents for sulfide minerals, with relatively good results.<sup>4,5</sup>

As previously mentioned, preliminary flotation studies on the various dithiocarbamate systems for the recovery of oxide uranium minerals eliminated the less suitable dialkyl, aromatic, and heterocyclic analogs. Hence a complete study of the more promising straight chain mono-alkyl dithiocarbamate compounds was made. A study of these compounds containing 4 to 18 carbon atoms in the attached hydrocarbon radical revealed that the carbon chains between 8 and 12 carbon atoms long were the most useful in this flotation research.

**Preparation of Collectors:** Care was exercised in preparing pure amines from the crude by fractionation of the organic compounds. It was then possible to prepare the dithiocarbamate series by gently refluxing the pure amine with carbon disulfide and the proper base to prepare the desired crude salt. The pure salt product, usually the potassium or sodium salt, was then isolated by repeated recrystallization from suitable solvents. The need for pure preparations became evident when it was found that on handling and storage the impure dithiocarbamates were unstable.

Consideration of salt modifications of these compounds resulted in narrowing the choice of metal ions to the alkaline or alkaline earth members. A further restriction to be placed on the use of the dithiocarbamate salts, although it does not appear to limit the activity of the above electrophilic centers, is that chelation between the dithiocarbamate grouping and the metal cation must be avoided. If such a chelation occurred, it would alter the solubility, the stability, and the chelating ability with the uranium mineral, and hence destroy most of the value of the salt complex as a collector.

**Use of Synthetic Minerals:** To evaluate correctly the collecting properties of the dithiocarbamates for uranium or other minerals, it is desirable to eliminate the many variables encountered in flotation of natural ores. For this reason synthetic minerals were prepared and mixed with ground silica sand to give a synthetic ore. Relatively pure autunite and carnotite have been prepared in the laboratory and these in turn have been altered to torbernite and tyuyamunite, respectively. In the alterations it is probable that only surface changes occurred.

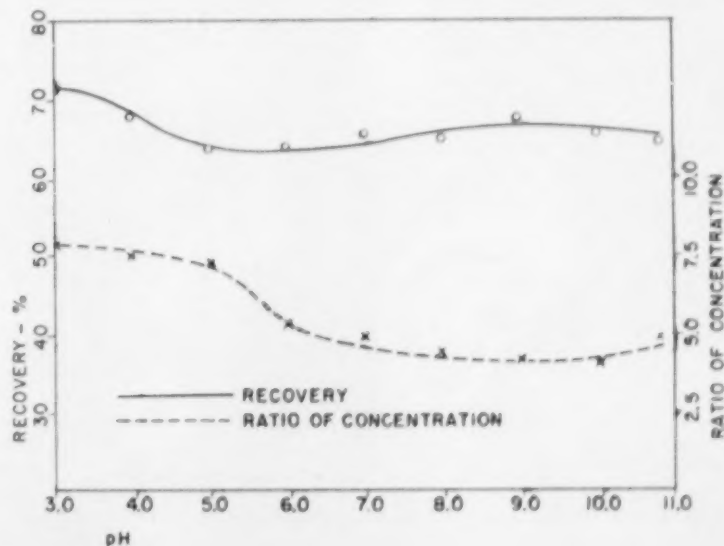
**Experimental Results:** Flotation tests in the early stages of this work were made on synthetic autunite because even with mixtures containing from 0.1 to 0.5 pct  $U_2O_5$ , the fluorescence of the autunite gave a convenient means of observing the progress of the flotation by lamping with an ultraviolet light. A standard test procedure was set up for single cycle batch tests as follows:

Synthetic ore: 5 g --225 M autunite mixed with 495 g --100 M silica sand	
Grind:	15 min in Abbe mill, to give the following screen analysis:
	+150 M                      7.7 pct
	+200 M                      37.3 pct
	-200 M                      55.0 pct
Pulp density:	17 pct solids
Conditioning:	5 min before each stage of flotation
Flotation:	three stages, 5 min, 5 min, and 10 min

After establishing a successful technique for floating autunite under the ultraviolet light, many of the tests applied to this mineral were repeated on synthetic carnotite. Since the carnotite floats as readily as the autunite, similar conditions were adopted for flotation of the carnotite.

**pH and Collector Studies:** Tests have been run on the dithiocarbamates to determine the effects of pH, carbon chain length, and salt modifications. Fig. 2 shows effects on recovery and ratio of concentration with pH changes from 3.0 to 10.8. In all tests three concentrates were floated, with staged additions of potassium N-mono-n-decyldithiocarbamate as the collector and American Cyanamid Reagent B-70 as the frother. Ammonium N-mono-n-octyldithiocarbamate, although giving good results in early tests, proved too unstable and therefore less desirable for salt preparations than potassium. Amounts of collector and frother were 0.6 and 0.4

Fig. 2—Effect of pH on recovery and ratio of concentration of synthetic autunite.



lb per ton, respectively, added to each stage. Fig. 2 shows that there is very little difference in recoveries for the pH range of 3.0 to 10.8; a slightly higher recovery was obtained at pH of 3.0 with a gradual decrease in recoveries as the pH was increased. Highest ratios of concentration were also obtained at a pH of 3.0, but these ratios were only slightly lower at pH of 6.0. From an overall consideration of recovery, ratio of concentration and froth conditions during floating, and uranium solubility, the best pH value for flotation with the dithiocarbamates proved to be 6.0. These results are shown graphically in Fig. 2.

Beaker flotation tests were used to investigate a number of salt modifications with carbon chain lengths up to 18 carbon atoms. From results of these tests the alkali metal ions proved to be the most satisfactory and the carbon chain length required for the best results was from 8 to 12 carbon atoms. Succeeding flotation tests were therefore concentrated on these compounds. Comparisons of results show that the potassium N-mono-n-decyl-dithiocarbamate gave the highest consistent recoveries when used as a collector at a pH of 6.0. The potassium salt with 12 carbon atoms in the hydrocarbon radical gave somewhat lower recoveries. The ammonium N-mono-n-octyldithiocarbamate gave good recoveries, but as previously mentioned it was unstable and unless tests were run with the freshly synthesized compound, the results were erratic. Also, as was to be expected, the ammonium salt proved even less stable when used for flotation in an acid pulp.

#### Surface Alteration of Minerals Before Flotation:

An important phase of this investigation has been a study of the possibility of altering the surfaces of the uranium minerals before adding the collector, in order to make them more amenable to flotation. The fact that autunite does undergo ion exchange

with a number of metal ions has been known for many years.<sup>7</sup> However, the conditions under which these exchanges were effected involved the use of concentrated solutions of the metal ions. For the purpose of this research it was necessary to learn more about the extent of ion exchange in relatively dilute solutions that would permit more economical usage of the metal ion in a flotation circuit.

Exchange studies were therefore made using 0.01 M solutions of the metal ions, and batch tests were run on autunite with solutions of copper, zinc, lead, and cadmium chloride, using small increment variations in the pH of each series from approximately 2 to 5. Polarograms were run on all solutions before and after exchange with the autunite. Maximum exchanges obtained for the calcium in the autunite were 10 pct with copper, 29 pct with zinc, 45 pct with lead and 23 pct with cadmium. The small amounts of altered autunite ( $\frac{1}{4}$  g) were later mixed with 500 g of silica sand, ground, and floated in the laboratory flotation cell, with ammonium N-mono-n-octyldithiocarbamate as the collector. Results of these tests showed that surface alteration with base metal ions before flotation produced considerably higher recoveries than when the unaltered mineral was floated. Recoveries of 96.7, 89.9, 81.0 and 74.2 pct were made on autunite treated respectively with lead, cadmium, copper, and zinc, as compared to 63.8 pct recovery on unaltered autunite. Additions of the same base metal salts to standard flotation tests in which 5 g of autunite in 500 g of silica sand were used showed the same marked effect, although recoveries were not in the same order. Recoveries obtained by direct additions of base metal salts to the pulp gave 99.8, 99.7, 99.2 and 98.9 pct, respectively, for additions of zinc, lead, copper, and cadmium, as compared to 95.6 pct recovery of the uranium when no base metal had been added. Effects of surface alteration and base metal additions on autunite flotation are shown in Fig. 3.

Base metal additions amounting to 3.0 lb per ton were made in the first tests run, but later tests showed that this could be reduced to 1.5 lb without materially lowering the recovery. A significant effect of adding the base metal salts is the increase in rate of flotation, although recoveries were also improved. Without the base metal salts, only 32 to 40 pct of the values were recovered in the first concentrate, while with the base metal salts the first concentrate accounted for 67 to 76 pct of the values. This is of great importance in plant flotation practice, where values in circulating loads must be kept to a minimum; it also reduces the required number of flotation machines for a given tonnage. In the first studies made on the effects of base metal salts, chlorides were used exclusively, and lead chloride was selected as giving the best results. Later work showed that lead nitrate was equally effective, and hence it was used because of its greater solubility.

Comparisons were made between the use of dithiocarbamates and oleic acid as collectors. Without the addition of base metals salts, recovery with oleic acid was much lower, with ratio of concentration approximately the same. With additions of lead nitrate before floating, the dithiocarbamates gave slightly higher recoveries than oleic acid, but ratios of concentration, with one exception, were consistently higher when dithiocarbamate was used. Also, when the pH was increased to a value of 8.0, oleic acid activated and floated most of the silica. Comparative figures are given in Table I.

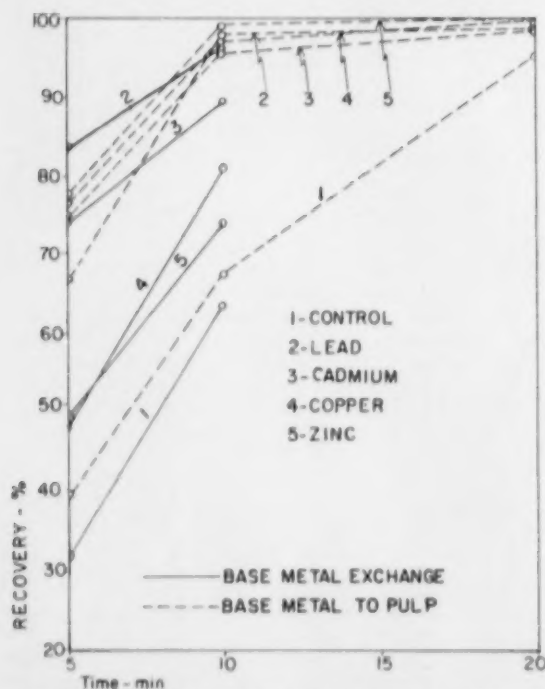


Fig. 3—Effect of base metal exchange on recovery of synthetic autunite.

**Frother Selection:** In using organic collectors such as the dithiocarbamates, selection of a frother that is compatible with the collector is important, primarily because of the possibility of direct reaction between the collector and the frother. It is also desirable to have a frother possessing minimum collecting properties. In early tests, methyl isobutyl carbinol (American Cyanamid Co. frother B-70) had been used and appeared to give good results. To establish definitely the best frother for this purpose, beaker flotation tests were run on 15 different frothers, and these tests narrowed the desirable frothers to three: B-70, B-77, and Dowfroth. A series of flotation tests run with these three frothers, using two different dithiocarbamates, showed all three to be good frothers. However, the B-70 reagent was finally chosen as it gave somewhat better froth conditions and recovery. Differences in ratios of concentration were undoubtedly due to experimental variations.

**Effects of Various Gangues:** While this phase of the work is not yet complete, preliminary investigations show that calcite, limonite, and kaolin, when added singly to a pulp of silica sand and synthetic mineral (autunite or carnotite), lower the recoveries. The gangue minerals also appear to be activated by both the dithiocarbamates and the base metal salts, with consequent lower grade concentrates. Nine to ten percent of lime (CaO) in the pulp lowers the recovery by only 1½ to 2 pct, but the ratio of concentration is reduced from 9.7:1 to 5.5:1, with 80 pct of the lime being floated.

Nine percent by weight of limonite added to the pulp reduces the recovery of uranium by more than

7 pct, with the ratio of concentration lowered about the same as with lime. In this case, however, only 40 pct of the limonite floated. Kaolin additions of more than 5 pct of the weight of the pulp materially reduced the recovery of the synthetic minerals and, in addition, abstracted lead salts from the pulp.

**Cyclic Tests:** A number of cyclic or locked tests were run on both synthetic autunite and carnotite, under the conditions established by the single batch tests. The optimum conditions for both these minerals are:

Grind	As shown previously
pH	6.0 ± 0.5
Collector	Potassium N-mono-n-decylthiocarbamate, 0.6 lb per ton added to each of three stages of conditioning.
Conditioning agent	Lead nitrate, 0.5 to 1.0 lb per ton, added to each of three stages of conditioning.
Frother	Methyl isobutyl carbinol (B-70), 0.4 lb per ton added to each stage.

Typical results obtained in cyclic tests on autunite and carnotite are given in Table II.

### Conclusions

The preliminary work on this study has shown that the normal aliphatic compounds consistently had better collector properties for the secondary uranium minerals than have the aromatic compounds. Also the mono-substituted normal aliphatic nitrogen loadings were more effective than the di-substituted nitrogen loadings on the dithiocarbamate function. Satisfactory flotation recoveries were obtained with chain lengths from 8 to 12 carbon atoms.

Surface alteration of the uranium minerals with base metal salts, especially lead, before addition of the collector, was effective in producing higher recoveries, better ratios of concentration, and more rapid flotation of the uranium minerals. Results of a number of flotation tests on synthetic minerals have shown recoveries of 90 pct or higher on feed assays ranging from 0.1 to 0.5 pct U<sub>3</sub>O<sub>8</sub>. Ratios of concentration up to 15:1 were possible. The effectiveness of the dithiocarbamates as collectors was not dependent upon close pH control, although the best working pH was between 6 and 8.

Tests run on natural autunite and carnotite ores have not yet produced as good recoveries and ratios of concentration, probably because slime coatings on the mineral surfaces prevent effective bonding of the collector.

### Acknowledgments

The authors wish to thank all members of the staff on this project for their help and cooperation, and especially H. J. Seim for his assistance on the base metal exchange work. They also express appreciation to the Raw Materials Div. of the U. S. Atomic Energy Commission for making this research possible and for permission to publish their findings.

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Discussion of this paper (2 copies) sent to AIME before Dec. 31, 1956, will be published in *MINING ENGINEERING* and in *AIME Transactions*, Vol. 208.

Table I. Comparisons Between Dithiocarbamates and Oleic Acid as Collectors

Mineral Flotted	pH	Base Metal Salts	Collector			
			Dithiocarbamate		Oleic Acid	
			U <sub>3</sub> O <sub>8</sub> Re-covered, Pct	Ratio of Concentration, Pct	U <sub>3</sub> O <sub>8</sub> Re-covered, Pct	Ratio of Concentration, Pct
Autunite	4.0	None	96.0	8.64	44.1	8.26
Autunite	4.0	Pb(NO <sub>3</sub> ) <sub>2</sub>	97.5	13.57	91.4	5.77
Autunite	6.0	Pb(NO <sub>3</sub> ) <sub>2</sub>	96.9	10.94	95.2	1.44
Autunite	8.0	Pb(NO <sub>3</sub> ) <sub>2</sub>	95.9	7.40	88.9	3.43
Carnotite	4.0	Pb(NO <sub>3</sub> ) <sub>2</sub>	87.1	16.13	78.9	16.13
Carnotite	6.0	Pb(NO <sub>3</sub> ) <sub>2</sub>	89.7	12.99	89.9	2.80
Carnotite	8.0	Pb(NO <sub>3</sub> ) <sub>2</sub>	88.8	8.33	90.7	1.02

Table II. Five-Cycle Flotation Tests

Product	Wt. Pct	Assays, Pct U <sub>3</sub> O <sub>8</sub>	Distribution, Pct U <sub>3</sub> O <sub>8</sub>	Ratio of Concentration
<b>Synthetic Autunite</b>				
Feed	100.00 (0.618)		100.0	
Recleaner concentration	3.74	13.325	80.6	26.7
Recleaner tailing	3.87	1.989	12.5	
Cleaner concentration (2 + 3)*	(7.61)	(7.561)	93.1	13.1
Cleaner tailing	2.24	1.338	4.6	
Rougher concentration (2 + 3 + 5)	(9.85)	(6.146)	97.9	10.2
Scavenger concentration	2.83	0.303	0.9	
Scavenger tailing	87.32	0.008	1.2	
<b>Synthetic Carnotite</b>				
Feed	100.00 (0.448)		100.0	
Recleaner concentration	2.87	9.547	61.1	24.8
Recleaner tailing	3.99	2.221	19.8	
Cleaner concentration (2 + 3)	(6.86)	(5.286)	80.9	14.4
Cleaner tailing	4.96	0.928	19.2	
Rougher concentration (2 + 3 + 5)	(11.82)	(3.457)	91.1	8.4
Scavenger concentration	3.98	0.040	5.7	
Scavenger tailing	84.20	0.017	3.2	

\* Weights and assays in parentheses are calculated values.

# Mineralizing Solutions That Carry and Deposit Iron and Sulfur

*It is suggested that at high temperatures both sulfur and iron combine with oxygen. Iron may precipitate at the high temperatures as the oxides of iron, and sulfur also in combination with oxygen as the low solubility sulfates of barium, strontium, calcium, and potassium (alunite). At lower temperature the precipitation results from change of sulfate sulfur to sulfide sulfur, and the iron precipitates as the sulfide.*

by B. S. Butler

**A**N understanding of mineralizing solutions and how they carry and deposit metals is of prime importance to students of ore deposits. Lindgren states: "The whole problem surely is very complicated. One difficulty is that we know so little about the stability field of ore minerals." Lindgren further states:

It is believed that they [the solutions] were in small part oxidized to sulphates, for instance, but in large part they were composed of hydrogen sulphide, alkaline sulphides and various halogen compounds. Doubtless, however, free carbon dioxide was present. Becker's view of the double sulphides as important constituents of the solutions probably holds good.

In the fourth edition of *Mineral Deposits*<sup>1</sup> Lindgren had changed his views somewhat:

From the work of Day, Allen, Shepard, and others, it would seem probable that many of the volcanic gases are acid when given off but are in unstable equilibrium, and could not have preserved this acid character after having been long in contact with the surrounding rocks. It is believed that they were in small part oxidized to sulphates, for instance, but in larger part they were composed of hydrogen sulphides, alkaline sulphide, and various halogen compounds. Doubtless, however, free carbon dioxide was present. Becker's view of double alkaline sulphides as important constituents of the solution probably holds good.

The writer wonders if progress would not result from an attack on the problem in steps, the steps to contribute to the attack on the whole. The initial

step would deal with the simpler bodies of supposed magmatic (hydrothermal) origin, that is, those composed essentially of silicates, oxides, sulfates, and sulfides. The following discussion attempts to develop one step of a method that was proposed on a more comprehensive scale in 1929 by the writer and W. S. Burbank.<sup>2</sup>

The accompanying partial table (Table I) of the electromotive series is from a table distributed by Merck & Co. Inc., manufacturing chemists, prepared in turn from *Fundamental Chemistry*.<sup>3</sup> The electromotive arrangement brings together elements that in hypogene ore deposits occur: 1) in oxygen combination only; 2) in combination with sulfur as well as with oxygen; and 3) as sulfides, arsenides etc., and as native metals, see Table II.

The writer clearly recognizes that he is not qualified to discuss the formation of ore deposits as a chemical problem, but he feels that some of the relations that are met by the geologist can well be stated with the hope that the chemical explanation will be forthcoming.

By consideration of a group including mainly the elements oxygen, hydrogen, sulfur and iron, complications are avoided, especially with elements of the lower electromotive group. The results can only contribute to the solution of the problem, not to the completion of it.

The pH and Eh of the solutions and also temperature probably determine what minerals form. The mineral groups that contain elements high in the electromotive series are aluminosilicates, titanites, simple silicates, spinels, oxides, carbonates and sulfates, in all of which the elements are combined with oxygen. These groups are also recognized as the general order of temperature at which the minerals start to form, see Table II. At low temperature are sulfides, arsenides, antimonides, sulfo-salts, and native metals, in all of which the elements are characteristically not combined with oxygen. The intermediate temperature group contains elements that form both oxygen compounds and sulfur compounds.

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TP 42681. Manuscript, Aug. 23, 1955. New York Meeting, February 1956.



This intermediate group follows the increasing tendency of elements going up the electromotive scale to form oxygen compounds and the increasing tendency of elements going down the scale to form sulfur and allied compounds. A glance at Table II shows that the minerals that form early are in the acid portion of the pH range and that the sulfides and allied minerals are in the alkali portion of the pH range. So arranged, the minerals form a zone crossing the chart from high acidity and high temperature in the upper northwest corner to alkalinity and low temperature in the lower southeast corner.

From the positions in the electropotential series, the general order in which the elements combine with oxygen is apparent. Two elements very common in hypogene ore deposits, and closely associated, are also close in the electromotive series, namely iron and sulfur. Ferric and ferrous-ferric (spinel, magnetite) oxides are abundant in the higher temperature deposits. Would sulfur also be expected in the oxidized state as  $\text{SO}_2$  or  $\text{SO}_3$  under conditions where iron is as  $\text{FeO}$  and  $\text{Fe}_2\text{O}_3$ ?

Until recently sulfates have not been so generally recognized as forming in the higher temperature group, but for some years there has been accumulating evidence of abundant sulfates in primary deposits. What evidence indicates that sulfates do form in that group?

#### Evidence in Mineral Occurrences

**A Constituent in Igneous Rocks:** Silicate-sulfate minerals as hauynite and noselite, of igneous rocks, contain the sulfate radical.

**Minerals in Ore Deposits:** Barite ( $\text{BaSO}_4$ ), least soluble of the common sulfate minerals, is common and in numerous deposits is an abundant gangue mineral. In many deposits it begins to form earlier than accompanying sulfides. Scores of examples of barite as a hydrothermal mineral could be cited but only two references will be used, the Tintic district, Utah,<sup>6</sup> of Tertiary age and the Mountain Pass district of California of Pre-Cambrian age.<sup>7</sup>

**Anhydrite-Gypsum:** Anhydrite has not been as generally recognized as a primary gangue mineral in hypogene ore deposits as has barite. The writer cited numerous examples in 1919,<sup>8</sup> and would appreciate the reporting of other occurrences. Many other examples are now known, some of which are given here: the Antamok mine of the Benquet Consolidated Mfg. Co., Philippines;<sup>9</sup> the Sulitjelma district, Norway;<sup>10</sup> the Potrerillos mine, Chile;<sup>11</sup> the Bully Hill district, California;<sup>12</sup> anhydrite with "contact metamorphic" minerals;<sup>13</sup> gypsum on the 2100 level of the Utica mine, Mother Lode district, California;<sup>14</sup> gypsum, celestine, and barite, Cripple Creek district, Colorado;<sup>15</sup> and gypsum at Antamok.<sup>16</sup> Harrison Schmidt's article "What Is Primary Sulphate?"<sup>17</sup> should also be cited. P. S. Haapala<sup>18</sup> describes the anhydrite complex of Morococha, Peru. There is dispute as to whether the origin is hydrothermal or sedimentary. Haapala regards the anhydrite as sedimentary.

It is of interest to note the occurrence of gypsum in the Enterprize blanket of the Rico Colorado district described by Rasmussen,<sup>19</sup> who regards the larger bodies of gypsum as remnants of a sedimentary bed largely removed by solution. This removal resulted in the formation of a slump breccia which was mineralized to form the ore deposit.

**Alunite:** The occurrence of alunite ( $\text{K}_2\text{O} \cdot 3\text{Al}_2\text{O}_3 \cdot 4\text{SO}_3 \cdot 6\text{H}_2\text{O}$ ), as well as other hydrothermal sulfates,

## ELECTROMOTIVE SERIES

REDUCTANT		OXIDANT	POTENTIAL
$\text{Cs}$	$\rightleftharpoons$	$\text{Cs}^+$	+3.02
$\text{Li}$	$\rightleftharpoons$	$\text{Li}^+$	+3.02
$\text{Rb}$	$\rightleftharpoons$	$\text{Rb}^+$	+2.99
$\text{K}$	$\rightleftharpoons$	$\text{K}^+$	+2.92
$\text{Ba}$	$\rightleftharpoons$	$\text{Ba}^{++}$	+2.90
$\text{Sr}$	$\rightleftharpoons$	$\text{Sr}^{++}$	+2.89
$\text{Ca}$	$\rightleftharpoons$	$\text{Ca}^{++}$	+2.87
$\text{Na}$	$\rightleftharpoons$	$\text{Na}^+$	+2.71
$\text{Mg}$	$\rightleftharpoons$	$\text{Mg}^{++}$	+2.34
$\text{Be}$	$\rightleftharpoons$	$\text{Be}^{++}$	+1.70
$\text{Al}$	$\rightleftharpoons$	$\text{Al}^{+++}$	+1.67
$\text{Mn}$	$\rightleftharpoons$	$\text{Mn}^{++}$	+1.05
$\text{Zn}$	$\rightleftharpoons$	$\text{Zn}^{++}$	+0.76
$\text{Cr}$	$\rightleftharpoons$	$\text{Cr}^{++}$	+0.71
$\text{Ga}$	$\rightleftharpoons$	$\text{Ga}^{+++}$	+0.52
$\text{S}$	$\rightleftharpoons$	$\text{S}$	+0.51
$\text{Fe}$	$\rightleftharpoons$	$\text{Fe}^{++}$	+0.44
$\text{Cd}$	$\rightleftharpoons$	$\text{Cd}^{++}$	+0.40
$\text{Ti}$	$\rightleftharpoons$	$\text{Ti}^+$	+0.34
$\text{Co}$	$\rightleftharpoons$	$\text{Co}^{++}$	+0.28
$\text{Ni}$	$\rightleftharpoons$	$\text{Ni}^{++}$	+0.25
$\text{Sn}$	$\rightleftharpoons$	$\text{Sn}^{++}$	+0.14
$\text{Pb}$	$\rightleftharpoons$	$\text{Pb}^{++}$	+0.13
$\text{H}$	$\rightleftharpoons$	$\text{H}^+$	0.00
$\text{Sb}$	$\rightleftharpoons$	$\text{Sb}^{+++}$	-0.10
$\text{Sn}^{++}$	$\rightleftharpoons$	$\text{Sn}^{++}$	-0.15
$\text{Bi}$	$\rightleftharpoons$	$\text{Bi}^{+++}$	-0.20
$\text{As}$	$\rightleftharpoons$	$\text{As}^{+++}$	-0.30
$\text{Cu}$	$\rightleftharpoons$	$\text{Cu}^{++}$	-0.34
$\text{As}^{+++}$	$\rightleftharpoons$	$\text{As}^{+3}$	-0.50
$\text{I}^-$	$\rightleftharpoons$	$\text{I}_2$	-0.53
$\text{Fe}^{++}$	$\rightleftharpoons$	$\text{Fe}^{+++}$	-0.75
$\text{Sb}^{+++}$	$\rightleftharpoons$	$\text{Sb}^{+5}$	-0.75
$\text{Hg}$	$\rightleftharpoons$	$\text{Hg}^+$	-0.80
$\text{Ag}$	$\rightleftharpoons$	$\text{Ag}^+$	-0.80
$\text{Hg}^+$	$\rightleftharpoons$	$\text{Hg}^{++}$	-0.91
$\text{Br}^-$	$\rightleftharpoons$	$\text{Br}_2$	-1.06
$\text{Cl}^-$	$\rightleftharpoons$	$\text{Cl}_2$	-1.36
$\text{Au}$	$\rightleftharpoons$	$\text{Au}^+$	-1.68
$\text{Bi}^{+++}$	$\rightleftharpoons$	$\text{Bi}^{+5}$	-1.70
$\text{F}^-$	$\rightleftharpoons$	$\text{F}_2$	-2.85

Table I. Partial table of elements in electromotive series. (After Merck & Co. Inc.)

was summarized in 1919 by the writer.<sup>8</sup> Since that time much has been published on alunite and allied minerals in the hydrothermal alteration of rocks associated with ore deposits. The results were summarized in a conference at the Colorado School of Mines recorded in the *Quarterly* of the Colorado School of Mines.<sup>20</sup>

One feature brought out in these and earlier papers is the great extent of alteration of rocks to alunite and the group of clay minerals that form under conditions allied to these producing alunite.

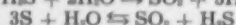
It was also pointed out that this group of minerals characteristically formed earlier than the sulfide minerals other than some possible pyrite. The type of alteration is that caused by acid solutions, and the sulfate of the alunite indicates that sulfuric acid was important in this process.

Special emphasis was given to the hydrothermal alteration of wall rocks associated with copper deposits. It can now be stated that the sulfate mineral alunite is a very important hydrothermal mineral accompanying ore deposition and that in large part, at least, it preceded sulfide deposition. Many occurrences of alunite could now be cited, but this is hardly necessary.

Other hypogene sulfate minerals of limited occurrence are Hinsdalite<sup>22</sup> ( $2\text{PbO} \cdot 3\text{Al}_2\text{O}_3 \cdot 2\text{SO}_3 \cdot \text{P}_2\text{O}_5 \cdot 6\text{H}_2\text{O}$ ) one of the few hypogene metal sulfates; Creedite<sup>23</sup> ( $\text{CaSO}_4 \cdot 2\text{CaF}_2 \cdot 2\text{Al}(\text{FOH})_3 \cdot 2\text{H}_2\text{O}$ ); and Thoumasite<sup>24</sup> ( $3\text{CaO} \cdot \text{SiO}_2 \cdot \text{SO}_3 \cdot \text{CO}_2 \cdot 15\text{H}_2\text{O}$ ).

**Occurrence in Fumaroles:** Fumaroles have been studied by members of the Geophysical Laboratory-Carnegie Institution of Washington and by many others. Ziess and Allen have shown that in high-temperature fumaroles, in the Valley of Ten Thousand Smokes,<sup>25</sup> sulfur is as oxygen gas  $\text{SO}_2$  or  $\text{SO}_3$ , at lower temperature as hydrogen sulfide ( $\text{H}_2\text{S}$ ). Sulfur is apparently a less abundant element in that area than is chlorine, but its behavior may be taken as typical. According to Ziess:<sup>26</sup>

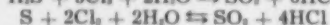
Allen and Ziess found that hydrogen sulphide and sulphur are most likely to be associated with the steam escaping from relatively low temperature vents ( $100^\circ\text{--}200^\circ$ ). It is well known, for instance, that hydrogen sulphide, sulphur, and steam will react at elevated temperature in the following manner:



These equations are likewise continually displaced from right to left as the fumarole gases progress from a region of high temperature to one of low temperature.

Ziess further states (Ref. 25, p. 10):

We have seen, for instance, that fumarolic gases contain sulphur, either as hydrogen sulphide or as free sulphur, both of which in an atmosphere of steam can readily be oxidized through the agency of chlorine. The reaction can go beyond the stage of oxidation



indicated in the equation for it is well known that sulphur trioxide ( $\text{SO}_3$ ) can be formed under these conditions, especially in the presence of large contact surfaces such as pumice affords.

From the occurrence of sulfate minerals in 1) igneous rocks, 2) ore deposits earlier than sulfate minerals, and 3) high-temperature fumaroles, and also from what can be inferred from the position of sulfur in the electromotive series, sulfates are to be expected and are found with the relatively high-temperature minerals, but not in great variety owing to the high solubility of most sulfates. Sulfur at low temperature in hydrothermal solutions is present as S or  $\text{H}_2\text{S}$ , though sulfates may persist at low temperature.

## Source of Oxygen

At high temperature, in magmatic solutions, a source of oxygen is  $\text{H}_2\text{O}$ , which at elevated temperature is an oxidizing agent for sulfur and hydrogen sulfide. Is sulfur in the magma and in high-temperature hydrothermal solutions as  $\text{SO}_2$  that can carry metals as sulfites or sulfates but do not precipitate metal sulfates because of the high solubility of the metal sulfates?

From such solutions the metals deposit as oxides—magnetite, for example—probably with the reduction of acidity. Magnetite deposits were formed in the high-temperature fumaroles of the Valley of Ten Thousand Smokes. As the temperature of the fumaroles lowered the oxides of sulfur,  $\text{SO}_2$  and  $\text{SO}_3$ , changed to hydrogen sulfide. In the  $\text{H}_2\text{S}$  solution the iron oxides already formed were not stable and disappeared, and the metals deposited at the lower temperature were sulfides. Hydrothermal solutions at high temperature deposit iron in oxygen combination, at lower temperature as sulfide. Is it reasonable to conclude, then, that 1) metals are carried at the high temperature as sulfites or sulfates and with decreased activity deposit as oxides and 2) that at lower temperature sulfate sulfur changes to sulfide sulfur and iron then deposits as sulfides?

## Supergene Ore Processes

It is instructive to compare the transportation of metals in supergene deposits with that in hypogene deposits. Supergene solution comes from the atmosphere. In addition to water ( $\text{H}_2\text{O}$ ) there are, in solution, in the water, nitrogen and oxygen of the atmosphere. The free oxygen dissolved in the water is the active agent. Such solution acting on an oxide deposit has little effect. Hematite and magnetite are slightly affected under weathering. On the other hand, a sulfide deposit, as pyrite or chalcocopyrite, is vigorously attacked.  $\text{FeS}_2$  is oxidized to  $\text{FeSO}_4$  and  $\text{H}_2\text{SO}_4$ , and further to ferric sulfate  $\text{Fe}_2(\text{SO}_4)_3$ , which speeds the oxidation process.  $\text{CuFeS}_2$  oxidizes to  $\text{FeSO}_4$  and  $\text{CuSO}_4$ , and the  $\text{FeSO}_4$  may further become  $\text{Fe}_2(\text{SO}_4)_3$ . The metals in solution move as sulfates. Replacing unaltered sulfide the copper is deposited as sulfide by replacing iron, and ferric sulfate oxidizes sulfide and is reduced to ferrous sulfate. Without going into further detail on the well known and much studied process of transfer of metals in supergene deposits, it may be said that to a large extent they move as sulfates from an oxidizing environment to a reducing environment. With reduction of acidity, ferric sulfate precipitates ferric hydroxide and yields sulfuric acid. The oxygen essential to this process is atmospheric oxygen. The metal sulfides are converted to sulfates and travel as sulfates. The process does not differ fundamentally from the previously discussed hypogene process except that, in the hypogene process, the temperature is high and water ( $\text{H}_2\text{O}$ ) furnishes the oxygen to form sulfates. At lower temperature  $\text{H}_2\text{S}$  develops as the precipitating agent for metal sulfides. In both processes the metals travel as sulfates and deposit as sulfides.

It is noteworthy that metals low in the electromotive series which do not form oxygen combinations in hypogene deposits do occur as oxygen minerals in the near surface zone of supergene alteration. In both conditions ferric sulfate is stable only

Table II. Elements arranged in order of their known or theoretical position in the potential series.  $\longrightarrow$

# NATURALLY OCCURRING COMPOUNDS OF ELEMENTS IN HYPOGENE DEPOSITS

	HIGH TEMPERATURE												LOW TEMPERATURE											
	ALUMINO-SILICATES	ZIRCONO-SILICATES	TITANO-SILICATES	TITANATES	BOROSILICATES	BORATES	COLUMBITES	TANTALATES	FLUORIDES	SIMPLE SILICATES	SPINELS	OXIDES	CARBONATES	SULFATES	SULFIDES	ARSENIDES	ANTIMONIDES	BISMUTHIDES	SULFO-SALTS OF ARSENIC	SULFO-SALTS OF ANTIMONY	SULFO-SALTS OF BISMUTH	TELLURIDES	SELENIDES	NATIVE METALS
Li	X																							
K	X																							
Rb	X																							
Cs	X																							
Na	X	X	X		X	X	X																	
Sr	X												X	X										
Ba	X		X		X								X	X										
Ra (?)																								
Ca	X	X	X	X	X	X	X	X	X	X			X	X										
Y (?)	X	X	X		X	X	X	X	X	X														
La (?)	X	X			X		X	X	X	X			X											
Be (?)	X									X														
Sc (?)																								
Ce (?)	X	X	X	X	X	X	X	X	X	X														
Th (?)										X														
Zr (?)	X	X	X		X	X				X														
Ti (?)	X	X	X	X		X	X					X												
U (?)							X			X	X	X	X											
Mg	X			X	X				X	X	X	X	X											
V <sup>II</sup> (?)	X									X														
Cb (?)							X	X																
Ta (?)			X			X	X																	
Cr <sup>II</sup> (?)	X		X		X	X				X	X													
Al	X	X	X		X		X		X	X	X	X												
Mn	X		X	X	X	X	X		X	X	X	X	X		X									
Sn <sup>IV</sup> (?)					X	X				X		X												
V <sup>III</sup> (?)																								
Mo (?)															X									
W (?)															X									
C (?)												X												X
Si (?)												X												
Zn					X					X	X				X									
Cr <sup>III</sup>	X									X	X													
S <sup>-2</sup>																								
V <sup>V</sup> (?)															X									
Fe <sup>II</sup>	X	X	X	X	X	X	X		X	X	X		X		X	X			X	X				X
N																								
Ga															X									
Cd												X			X									
In															X									
Tl <sup>I</sup>															X				X	X		X	X	
Co <sup>III</sup>										X		X			X	X			X	X	X	X	X	X
Ni <sup>II</sup>										X		X			X	X	X		X	X	X	X	X	X
Sn <sup>II</sup>															X				X	X	X	X	X	X
Pb										X					X				X	X	X	X	X	X
Fe <sup>III</sup>	X				X					X	X	X			X									
Ge (?)															X						X			
H												X	X	X	X									X
P (?)																								
Ru (?)															X									X
Sb										X					X					X				X
Bi <sup>III</sup>										X					X						X			X
As <sup>III</sup>										X					X				X					X
Cu <sup>II</sup>										X					X				X	X	X	X	X	X
Te (?)																								
Cu <sup>I</sup>										X					X	X	X		X	X	X	X	X	X
Rh (?)																								X
I																								
S (?)																								X
Se (?)																								X
Hg															X				X	X	X	X	X	X
Ag															X		X	X	X	X	X	X	X	X
Pd (?)																								X
Au <sup>III</sup>																								
Au <sup>I</sup>																						X	X	X
Os (?)																								X
Ir (?)																								X
Pt (?)																X								X

OXYGEN COMPOUNDS ONLY

OXYGEN AND SULFIDE COMPOUNDS

SULFIDE COMPOUNDS, NATIVE METALS, ETC.

pH

LEGEND — X ABUNDANT OR COMMON MINERALS OF THE ELEMENTS  
 \* LESS COMMON MINERALS OF THE ELEMENTS

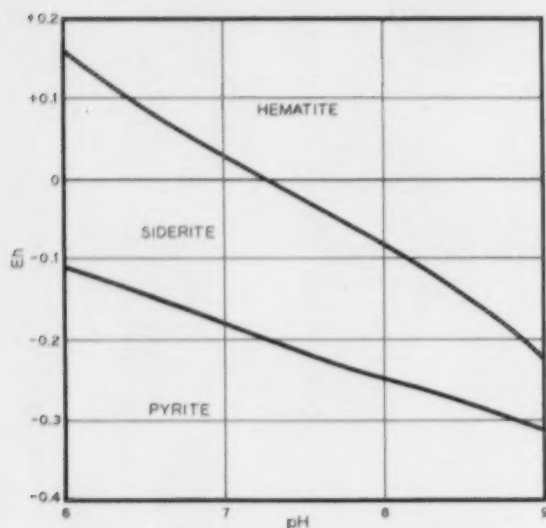


Fig. 1—Stability of hematite, siderite, and pyrite. (After Krumbein and Garrels.<sup>10</sup>)

in acid solutions, and when solutions approach neutral or alkaline, ferric oxide may precipitate as hematite or magnetite from high-temperature solutions, and limonite, or hydrous ferric oxide, from low-temperature solutions.

It may be noted that in the oxidation of sulfide bodies, the sulfur present as sulfide is largely carried away. Great bodies of sulfide have been oxidized, as at Bizbee, Ariz., with the sulfur removed from the vicinity, though the metals remain in part.

Krumbein and Garrels<sup>10</sup> show that the formation of chemical sediments, and the ores that are chemical sediments, are probably subject to control similar to those controls that affect the hydrothermal ores and those that result from supergene alteration of hydrothermal ores. The waters from which such sedimentary deposits are precipitated may be regarded as ore solutions. The field of stability of hematite, siderite, and pyrite are shown in the diagram, Fig. 1. The authors<sup>10</sup> state that the change in minerals is largely controlled by the change in pH and Eh of the solution.

Harold L. James,<sup>11</sup> in describing the sedimentary iron formations of the Iron River district, Michigan, states, "The rocks are believed to be the products of an era of iron rich sedimentation in which the specific iron minerals formed—sulfide, carbonate, or silicate—depend upon the immediate depositional environment. Evidence is presented to show that the climate of the era, when linked with other factors, is entirely adequate to explain the formation of these iron-rich rocks." An extensive reference list accompanies the article.

In the great sedimentary iron deposits the pyrite stage is not conspicuous and may not always be present, but the possibility of its being present seems definite.

The order follows that in iron deposits of other geological origins, all seem subject to a common control. It is simple and logical to conclude that oxygen controls the transfer of iron in the above mentioned environments and that the iron is in oxygen combination at high temperature or under oxidizing conditions at any temperature. Sulfur is also in oxygen combination at high temperature but changes

to sulfide at lower temperature—or under reducing conditions at any temperature—and iron then precipitates as sulfide.

It is obvious that this is not the only method in which metals are transported and precipitated to form ore deposits, but to the writer it seems to represent a method that is understandable and to a considerable extent observable.

A treatment of the elements in the lower range of the electromotive series, including chlorine and fluorine, is essential. Finally, the whole range must fall into a general system.

If this presentation is regarded as over-simplified, it is deliberately so. The writer prepared this paper with the hope that it will lead to contributions in the form of discussion. In the regular course of procedure the paper was referred to critics (identity unknown to the author). One of the critics made comments so keen and penetrating that the writer has added his general comments as discussion:

The thesis that there is a tendency for the metals to precipitate more commonly in oxygen combination at high temperature fits the facts, but perhaps it should be emphasized that transport is presumed to be as free metal in acid solutions. Also, the sulphur presumably is carried as dissolved sulfur in oxygen combination. Reduction of sulfate sulfur to sulfide sulfur goes at a finite rate only above 200°C (admittedly by laboratory experiment only), but it should be pointed out that below 200° the difficulty of sulfate reduction exists. For example, it would probably be very difficult to account for the pyrite of the Wisconsin lead-zinc deposits as a result of reduction of sulfate to sulfide at 100-150°C, with resultant precipitation of ores as sulfide.

Another aspect of interest is the reducing agent necessary to change sulfate to sulfide. The reactions cited depend upon water, but again it is doubtful that reaction between sulfate and water to produce sulfide could or would take place at temperatures of the order of magnitude of 200°C. In general the effects of low temperature ore fluids are to reduce the containing rocks—that is to say, the country rock is apparently not a sufficiently strong reducing agent to cause the sulfate-sulfide reduction; instead it is reduced by the ore fluid.

In summary, Dr. Butler's general thesis that the metals are carried as soluble sulfates at high temperature and pressure, and are precipitated as sulfides by a reduction of sulfate to sulfide with decreasing temperature and pressure, is one of the major suggestions for a mechanism to account for the transport of metals in company with sulfur. His statement of the problem, and particularly his documentation of the tendency to form minerals in higher states of oxidation under extreme conditions, is an important contribution. As he indicates, the reactions involved need to be worked out quantitatively. Data are badly needed on the changes of oxidation potential of the elements with ascending temperatures and pressure. The remarkable system of behavior shown in Table II, when potentials at 25°C and 1 atmosphere pressure are plotted against occurrence, is highly suggestive, and perhaps this paper may lead to the working out of the electromotive series under conditions more nearly resembling those of the formation of ores.



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# Acid and High Analysis Fertilizer Production From Western Phosphate Rock

by Robert J. McNally

THERE are three primary plant nutrients—nitrogen, phosphorus, and potassium—expressed in any fertilizer compound as percent N, percent  $P_2O_5$ , and percent  $K_2O$ , in that order. This article will be concerned with the first two.

The chief source of  $P_2O_5$  is phosphate rock. As found in the western states phosphate rock is essentially tricalcium phosphate-calcium fluoride (fluorapatite). As such, it is quite water insoluble.

The principal phosphate fertilizer used is single superphosphate, produced by reacting sulfuric acid with phosphate rock in the proper proportions. The mixture, which soon sets into a hard mass, is primarily diluted with calcium sulfate and contains 16 to 22 pct available plant food expressed as  $P_2O_5$ . The hard mass is aged for several weeks, ground, and shipped in bulk or in 80-lb. bags.\* Superphosphate

\* Several million tons of this material were produced during the 1953-1954 fertilizer season.

can be ammoniated to impart nitrogen value to the fertilizer.

Numerous small plants in the southeast and east north central part of the country supply large consuming local areas, where freight costs are a small part of the total cost of the fertilizer. Since the freight rate per ton of superphosphate is constant,

it is desirable to make high-strength superphosphate for distant shipments. A grade called treble or triple superphosphate, containing 42 to 47 pct available  $P_2O_5$ , is being produced in increasing amounts. This contains the same phosphatic material as single superphosphate, that is, monocalcium phosphate, but is nearly free of the calcium sulfate diluent.

**Western Phosphates:** Demand and consumption of high analysis phosphatic fertilizers has been growing steadily over the past five years. This is particularly true in the West and Midwest, where shipping distances are long. Until this year there have been insufficient phosphate fertilizers to meet demands, particularly in the Midwest, but supply has temporarily exceeded demand, since new producers have increased production rate.

The two raw materials necessary for production of superphosphate—sulfuric acid and phosphate rock—are produced in the Intermountain area. Garfield Chemical & Mfg. Corp., a subsidiary of Kennecott Copper and American Smelting & Refining Co., produces sulfuric acid from waste gases from smelting copper ores at Garfield, Utah. Phosphate rock is mined by the San Francisco Chemical Co. at various locations in the Tri-State area (northern Utah, southeastern Idaho, and southwestern Wyoming) where reserves are thought to be the largest in the world.

Raw material cost is the major item in producing superphosphates; transportation cost of phosphate rock is less than the transportation cost of sulfuric

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acid. With power, water, and transportation facilities available at Garfield, it was logical to form a company to produce phosphatic fertilizers near the source of these raw materials, situating a new plant near Garfield where delivery of sulfuric acid could be made by pipeline.

#### Formation of Western Phosphates Inc.

Western Phosphates Inc. was formed in September 1952, Stauffer Chemical Co. having 50 pct interest and the parent companies of Garfield Chemical & Mfg. Corp. each having 25 pct interest. Stauffer Chemical Co. was responsible for designing, building, and operating the plants to produce phosphoric acid, triple superphosphate, and ammonium phosphates and for selling this production. Construction was started at once and operation of the phosphoric acid plant began Jan. 13, 1954. Garfield Chemical built a new 250-tpd sulfuric acid plant and additional gas cleaning facilities to furnish the necessary sulfuric acid for the phosphate plant.

**Disadvantages of Western Rock:** The major difference between western phosphate rock and Florida rock is the  $P_2O_5$  strength and organic content. Strength of the Florida rock commonly used in making phosphatic fertilizers is 30 to 36 pct  $P_2O_5$ . The run-of-mine western acidulation grade rock and beneficiated concentrates is usually 31 to 32 pct  $P_2O_5$ . Alumina, iron, organic, and sodium, all objectionable impurities, are generally greater than in Florida rock. Mining costs, also, are higher in the West, particularly where underground mining is necessary.

**Products:** In the Western Phosphate method of producing treble superphosphate, phosphate rock is first reacted with sulfuric acid to produce phosphoric acid and calcium sulfate. The solid calcium sulfate is separated from the liquid phosphoric acid by filtration. The acid is produced at a strength of 26 to 32 pct  $P_2O_5$ . Clear acid from the filter is concentrated to 52 pct  $P_2O_5$  by evaporation and reacted with more phosphate rock to produce triple superphosphate. The resulting mix solidifies almost immediately into a porous mass, which is broken up and made into pellets. As in single superphosphate production, the fertilizer is then aged for at least 30 days to complete the reaction between phosphate rock and the phosphoric acid. During this aging period the free acid content of the triple decreases to less than 1 pct and the available  $P_2O_5$  increases. It is sold by Western Phosphates Inc. on a guaranteed analysis of 46 pct available  $P_2O_5$ . To upgrade the strength of single superphosphate, some concentrated 52 pct  $P_2O_5$  phosphoric acid is sold to single superphosphate acidulators. Recently it has also been applied directly to the soil, particularly where anhydrous ammonia is being directly applied.

Plants need both nitrogen and phosphorus, but different plants require different relative amounts of each component, and during a growing season a single type of plant requires these components in different ratios. In complete inorganic fertilizers, the nitrogen is supplied principally by ammonium sulfate, ammonium nitrate, urea, or ammonium phosphates, these latter compounds supplying both nitrogen and phosphorus in a single compound.

In previous years a great deal of the phosphatic fertilizer sold was in the form of single or triple superphosphate. Nitrogen was added in the form of one or more of the compounds mentioned. In the last few years the trend has been more and more

toward the ammonium phosphates, and pelletized fertilizers containing various ratios of nitrogen and phosphorus are being demanded by consumers and mixers in preference to single ingredient fertilizers. Some of the most popular grades are 16-20-0, 11-48-0, 13-39-0, and 27-14-0.

**Plant Size:** A necessary starting material for both triple superphosphate and ammonium phosphates is phosphoric acid. The minimum economic size wet process phosphoric acid plant is one consuming 150 tpd of phosphate rock. A more economic size, consuming 300 to 350 tpd, will consume 238 to 278 tpd of 100 pct  $H_2O_4$ .

**Phosphate Rock Handling:** At Western Phosphates Inc. the phosphate rock is received as dry concentrates and crushed rock containing up to 6 pct moisture. The concentrates are fine, all -30 mesh and about 45 pct -100 mesh. The crushed rock is all through  $\frac{3}{4}$  in. For ease in year-round handling these rocks have been received separately and also as a 50:50 mix. The crushed rock, received from April to October, is stockpiled outdoors in piles for blending, and concentrates are stockpiled in a covered storage building. At rated capacity 150,000 net tons will be consumed per year. The rock is received in closed and open hopper bottom railroad cars, discharged through a grate-covered track hopper, elevated, and transported by belt conveyors to the storages. Reclaim has been by Sauerman dragline from the inside storage and bulldozers from outside storage.

Phosphate rock is ground in two 72-in. Raymond mills, six rolls high, equipped with whizzers. Each mill has a gas-fired (or oil-fired) heater to furnish hot air for drying the rock in the mill when necessary. Phosphate rock for phosphoric acid production is ground to 50 to 60 pct -200 mesh, and for treble superphosphate manufacture 90 to 95 pct -200 mesh.

**Phosphoric Acid Production:** In production of phosphoric acid at Garfield, phosphate rock is quick-mixed with wash acid from the filter and dropped into an agitated digest tank along with prediluted sulfuric acid. Reaction is rapid with the production of gypsum and phosphoric acid, and wash water return is regulated to produce 27 to 32 pct  $P_2O_5$  acid. There are many impurities in the phosphate rock which also react with the sulfuric and phosphoric acids: iron and aluminum compounds are dissolved to their solubility limits as phosphates; calcium carbonate forms gypsum and carbon dioxide, consuming sulfuric acid without benefit; and fluorides and silica react to form fluosilicic acid. Some fluorine, driven off as silicon tetrafluoride, is scrubbed and collected by means of water jet condensers. The gypsum-phosphoric acid slurry overflows to two additional digesters in series for completing the reaction and growth of gypsum crystals. To control the temperature of the first digester, and also because considerable heat is evolved in the reactions, prior to filtration the slurry must be cooled in a Carrier vacuum flash cooler. A high recirculation rate of 2500 gpm is maintained. The major portion of the slurry is returned to the first digester, not only for temperature control but also to furnish gypsum nuclei for further growth to prevent formation of new small crystals. A portion of the slurry is removed from the discharge of the cooler and flows through two more digesters in series. Digester retention time calculated on a new feed basis should be 3 to 5 hr. From the last digester the slurry is

pumped to a filter for separating the phosphoric acid from the gypsum, which is washed three times on the filter, discharged at 70 pct solids, and sluiced to a settling pond.

The final wash of the gypsum is with hot water. This third wash is recycled over the filter counter-current to the gypsum flow, forming progressively stronger washes. The first wash, at about 20 pct  $P_2O_5$ , is returned to the first digester.

**Prayon Filter:** To separate gypsum from phosphoric acid Western Phosphates Inc. uses a filter of Belgian make, the first Prayon filter to be used in this country, although several have been in service in Europe for many years. The Prayon filter is a horizontal disk vacuum filter divided into 24 individual pie-shaped sections 71 in. long, 35 in. wide at the inner edge, 53 in. wide at the outer edge, and 8 in. deep. Mounted on wheeled carriages that travel on circular tracks, the sections are individually tilted and turned upside down for cake discharge. While the filter is upside down, the saran cloth filter medium receives a water wash from a series of jets to prevent scale build-up in the pores and on the surface. Cloth life is two to four months. The filter does occupy considerable space for effective filter area, which is 425 sq ft.

The largest made by Prayon, the filter is especially adapted to this service.\* Chief advantages are

\* Recently the Bird Machine Co. took over the rights for manufacture and sale of these units in this country.

complete cake removal, continuous cloth washing, drying of the cloth after washing, separation of washes, and effective counter-current washing with a minimum of water. Loss of soluble  $P_2O_5$  at Western is 1 to 2 pct. The filter operates at 18 to 20 in. of vacuum, supplied by Nash H-7 vacuum pumps.

**Acid Concentration:** Concentration of the filter grade acid to 52 pct  $P_2O_5$  is accomplished in Carrier falling film vacuum evaporators. Here too, as in filtration, Western Phosphates Inc. has pioneered in using equipment in a new service in this country. The Carrier unit is a conventional vertical heat exchanger consisting of a shell, tube sheets, tubes, inlet channel (at the top), and separation chamber. All wetted parts are of type 316 stainless steel. Liquid is pumped from a hot well to the inlet chamber, where it falls through a perforated distribution plate onto the top tube sheet. Here it is distributed and flows down the tubes in a falling film, along with released vapor, into the bottom vapor separator. The two tubes are 14 gage, 3 in. OD, and 20 ft long, each having 1840 sq ft of heat transfer surface. Periodically they are washed for about 8 hr to remove scale.

The concentrated acid returns to the hot well and is recycled. A portion is constantly pumped to storage, with fresh weak acid entering the agitated hot well, regulated by level control. Flow through the evaporator is 135 times the volume of the product made so that the increment concentration across the evaporator is low. This is important to minimize gypsum and fluosilicate scaling.

Vacuum is furnished by vacuum water condensers and steam jets. Steam is produced in a 25,000-lb per hr gas-fired vertical steam boiler generating at 150 psig and enters the shell at 5 psi. The evaporation operation is automatic and requires little attention.

**Operating Problems:** Major operating problems are fluosilicate and gypsum scaling (particularly in the central valve of the filter and in pipelines) and

corrosion. Where phosphoric acid must be in contact with metal, alloy 20 and type 316 and 317 stainless steel are used. Type 316 is a borderline metal in this service where there is much temperature.

The highly variable nature of the phosphate rock makes digester control difficult. Bedding of the rock to minimize erratic variations has helped control this problem, and various types of packless pumps are used, depending on the service.

**Treble Superphosphate Production:** The 52 pct  $P_2O_5$  phosphoric acid is heated and mixed at a controlled rate with phosphate rock weighed in continually. Vigorously mixed in a specially designed mixer, this fluid is dropped into a revolving den, setting in about 45 sec. As the den revolves the fresh treble is excavated continuously. The crumbled treble is belt fed to a continuous pelletizer, with a very small amount of water, to form pellets of 1/16-in. diam. From here the pellets are belt conveyed to storage, where they are aged for at least 30 days. The loosely set piles are then excavated with front end loaders and returned to the manufacturing building, where the product is dried in 8x60-ft rotary gas-fired dryers to 3 to 4 pct moisture. The pebbles are screened in Symons-type V-screens on 7 mesh, the coarse fraction passing through a Pennsylvania hammer mill and back over the screens. The treble is packed in 80-lb paper bags on two type-327PB St. Regis packers at 60 tons per hr and conveyed on Rapid Standard conveyors to truck loading or car loading stations. Some is shipped in bulk in box cars.

Nearly all treble and high-strength mixes are being produced as pellets. Even some of the producers of single superphosphate are changing from ground pellets to pellets. Advantages are: ease in handling; less surface contact, which minimizes caking; ease of application by the user; and slower solution rate in the ground. In the case of mixed fertilizers, a more homogeneous product results.

**Ammonium Phosphates:** Ammonium phosphates are made by reacting various ratios of sulfuric and phosphoric acids with ammonia in stainless steel agitated tanks. A thick, syrupy magma is formed which is mixed with dry ammonium phosphate, building up a thin shell on each particle. The slightly damp pellets are returned to the dryer for removal of the introduced water. The dried material is screened, and the fines and ground oversize are returned to the mixer along with a large percentage of the material in the product range. A portion is removed to storage. Circulating load is controlled at 10 to 12 times the amount being taken off as product. High nitrogen fertilizers such as 27-14-0 require ammonium nitrate as one of the ingredients.

**General Considerations:** Normally Western Phosphates Inc. employs a crew of 85 hourly workers, of which 30 are maintenance employees. During the heavy shipping season up to 25 workers are added to the shipping crew.

Power is purchased from Utah Power at 44,000 v. This is stepped down to 4160 v in a primary set of transformers and distributed to various operating centers in underground conduits, where it is transformed to the operating voltage of 440 v. Since the gypsum in the phosphoric acid digesters would settle out rapidly with a power failure, auxiliary standby power is available. This is provided by a 125-kva Delco diesel alternator unit and a 150-kw Elliott geared steam turbine generator, which automatically comes on line in the event of power failure.



These two are sufficient to operate the boiler, lighting load, and digester agitators.

**Future:** The fertilizer industry in the West has been growing rapidly. Installed capacity for ammonia production has been increased substantially, with two new plants scheduled this year in the U. S. and one in Alberta, Canada. Phosphoric acid, produced from phosphate rock and sulfuric acid, is also in far greater abundance than a few years ago. The fertilizer market for both nitrogen and  $P_2O_5$  is temporarily out of balance with production capacity.

More food must be raised on less land for a growing population. It must be done at a profit that requires higher yields. Crop response to nitrogen-containing fertilizers has long been recognized, and demonstrations that nitrogen and phosphorus supplement each other are increasing sales of fertilizers containing both these ingredients. Government

agencies and agricultural colleges have shown the economy of pastureland fertilization for high hay crop yields and beef production, and heavy farming of land in the Southeast has clearly proved that as new land is extensively farmed, naturally occurring fertilizer compounds are exhausted and more fertilizer must be applied.

A nationwide trend of producing more and more complete fertilizers in pelletized form is likely to expand. A greater number of different mixtures to fit exact fertilizer needs will be produced in higher tonnages, and more and more of the fertilizer requirements will be supplied in high-strength mixtures of nitrogen and phosphorus.

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# The Domestic Graphite Supply Problem

by E. N. Cameron

**G**RAPHITE has been included in U. S. lists of strategic minerals since the problem of mineral deficiencies was revealed during World War I. Since 1918 the domestic graphite industry has led a precarious existence, and there has been much uncertainty as to the amounts of usable graphite of various grades that would be available from domestic sources in time of emergency. In 1950-1951 therefore, the writer, assisted by Paul L. Weis, undertook a review of domestic graphite sources for the U. S. Geological Survey.<sup>1</sup> The conclusions of this study are presented here, with a discussion of some technologic and politico-economic factors bearing upon the problem.

**Uses of Graphite:** Natural graphite as marketed exhibits a wide range of properties, which determine the uses to which it is put. The most essential uses are in the manufacture of crucibles and related refractory articles, in lubricants and packing materials, and in the manufacture of batteries, foundry facings, pencils, and carbon brushes. Numerous specifications covering the mineral in its various applications must be met by producers and processors of graphite. The problem of supply is therefore not simply one of procuring a sufficient total tonnage, but the more difficult problem of procuring enough of each different grade to meet foreseeable needs.

The amount of graphite required by American industry is not large. Ordinarily only a few thousand tons of strategic grades are consumed annually, yet the elimination of this small tonnage would have serious effects in several industries.

**Strategic Graphite:** Since World War I, 60 to 100 pct of the country's annual supply of graphite has

been furnished from imports. At present, natural amorphous graphite for use in pencils and batteries is produced largely from American-owned mines in Mexico. Graphite for foundry facings is obtained from a number of sources. Neither grade is a serious problem. High purity graphite for carbon brushes and for pencil leads, however, is imported, largely from Ceylon, in the form of amorphous lump graphite. Most of the flake graphite used for crucibles and related refractory articles is likewise imported, largely from Madagascar, and much of the lubricant and packing grade graphite used by industry is obtained from the same source. The strategic grades of graphite are therefore amorphous lump of the Ceylon type, crucible flake, and flake suitable for lubricants and packing. Ceylon lump and Madagascar flake have for many years been accepted as standard by domestic consumers of graphite, and various essential manufacturing processes are geared to the use of graphite from these sources.

Ceylon graphite as marketed is classified into several grades based on particle size and purity. Processing methods are said to be simple, but the products marketed are carefully graded and are consistent in their characteristics, an important matter to the consumer. Nearly all the graphite produced in Ceylon is from veins. Resources are reported to be large, labor is cheap, production costs are low, and world competition is slight—factors accounting for the commercial success of the graphite mining industry in Ceylon.

Madagascar is reported to have deposits of the Ceylon type, but its output consists almost entirely of flake. Madagascar graphite as received in the U. S. is further processed by importing organizations, and a large number of grades are produced to meet industry requirements, especially those for crucible flake and for lubricant and packing grade flake. Madagascar crucible flake as marketed is noted for coarseness, uniformity, toughness, clean-

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ness, and other properties considered desirable by consumers. The deposits of the island are said to be large and numerous and have been reported to average from 8 pct to more than 30 pct flake graphite. Mining methods are simple, labor is cheap when available, and production costs are low. Madagascar graphite therefore holds a strong competitive position in world trade.

**Domestic Graphite Resources:** In the U. S., graphite occurs in many areas, and certain deposits in Montana, Texas, New York, Michigan, Alabama, Rhode Island, and Pennsylvania have been mined at various times since the latter part of the 19th century. Production since 1939, however, has come largely from single mines in Texas, New York, and Rhode Island, and from three mines in Alabama, although a mine in Pennsylvania and another in Montana have been operated for short periods.

Deposits near Dillon, Mont., are the only ones known in the U. S. as a possible source of Ceylon-type graphite. Reserves in these deposits are small, but additional reserves might be established by exploration. The deposits are not known to have yielded high purity graphite suitable for carbon brushes, and although this grade might be obtained by appropriate milling, it is not certain that domestic requirements for carbon brush graphite could be met from this source, even for a short time.

Flake graphite has been produced in substantial amounts from deposits in Burnet County, Texas; Clay, Coosa, and Chilton counties, Alabama; Chester County, Pennsylvania; and Essex, Warren, Saratoga, Washington, and St. Lawrence counties, New York. The products have been marketed at one time or another for almost every purpose for which graphite is used, but the chief use of domestic graphite since World War I has been for batteries and foundry facings. Attempts by domestic producers to enter the market for crucible flake have had little success, and most domestic producers have likewise had difficulty in competing in the market for lubricant and packing grade flake. One reason is that domestic operators ordinarily have not been able to meet the low price of Madagascar flake graphite delivered at New York. A second reason is a strong preference for Madagascar flake in the consuming industry. This preference exists partly because Madagascar has been a reliable source of uniform flake and partly because the best Madagascar flake is coarser and is generally considered to have more desirable physical properties than domestic flake. Uniformity of flake is important. There have been complaints that domestic flake graphites from some sources have varied in properties from shipment to shipment. A large share of domestic flake produced since 1939 has been aided by government subsidies.

The deposits of flake graphite in Texas, Alabama, New York, Montana, and Pennsylvania have been discussed repeatedly in the literature,<sup>2-4</sup> and deposits in these states have been investigated at various times since 1939. F. C. Armstrong and R. P. Full,<sup>5</sup> L. W. Currier,<sup>6,11</sup> R. H. Jahns,<sup>11</sup> and W. S. White<sup>12</sup> also have contributed information on graphite deposits in these states. In Alabama the USBM did extensive trenching and sampling of deposits during World War II, giving estimates of tonnage and graphite content of a number of deposits.<sup>13</sup> In Pennsylvania the Benjamin Franklin deposit was opened up and mined briefly under government auspices, and trenched, drilled, and sampled by the USBM in 1948.<sup>7</sup> Experimental mining

and milling are reported to have been done during 1953 and 1954 at the same deposit.<sup>14</sup> Much information on domestic resources of flake graphite is therefore available. Since most flake graphite deposits are relatively simple in structure, it is not difficult to estimate tonnages within the usual limits imposed by availability of exposures, drillholes, and excavations. Similarly, in the common types of deposits the average content of flake graphite can be determined within satisfactory limits. Most graphite deposits are as yet exposed or explored only to shallow depths. Present estimates are therefore incomplete, but they indicate clearly that resources of rock containing 2 to 8 pct flake graphite in the deposits of Texas, Alabama, Pennsylvania, and New York are very large. In Alabama, for example, on the basis of work by the USBM, Palister and Thoenen<sup>15</sup> estimate that measured reserves of weathered ore alone amount to 11,059,000 tons containing about 60 lb of recoverable flake of all grades per ton, or about 332,000 tons of recoverable graphite.

Such figures for overall size of domestic resources are impressive. Measured against the average annual American consumption of less than 10,000 tons of flake graphite per year, they suggest that domestic resources are more than ample for the country's needs and that the only obstacles to self-sufficiency are costs of production that are high relative to market prices for graphite.

The principal question involved in appraising domestic flake resources, however, is how much of the graphite recoverable would meet industrial requirements for the strategic grades of flake. As far as the writer has been able to determine, this question has not yet been fully answered for any sizable deposit in the U. S., and until the answers for a number of deposits are forthcoming, the adequacy of the country's resources cannot be appraised. This does not mean that strategic grades of flake cannot be obtained from domestic deposits, but only that no one knows at present how many of these grades can be produced or in what amounts.

**Usability of Domestic Flake Graphite:** The substitution of domestic flake for Madagascar flake has been debated for many years, and tests of domestic graphite products for use in crucibles have been made from time to time.<sup>3,4,16-22</sup> Investigations prior to World War II were partly in terms of technologic procedures now outmoded, and all were limited in scope. Apart from Coe's study of burning rates,<sup>3</sup> the only modern investigations thus far published are those cited by Sanford and Lamb<sup>16</sup> and the study by Heindl.<sup>23</sup> Data given by Sanford and Lamb cover commercial trials of clay-graphite crucibles manufactured wholly or in part from flake from several mines in Alabama and one mine in Pennsylvania. Results of the trials were decidedly adverse to the domestic graphites. As Sanford and Lamb pointed out, however, the tests were not sufficiently comprehensive to be conclusive.

Heindl has reported results of comparative tests of flake graphite from Madagascar, from a shipment of Alabama graphite forming part of the government stockpile, and from the Benjamin Franklin mine in Pennsylvania. From each lot of graphite, flake products were prepared by screening into various sizes and combining the size fractions in proportions specified by two crucible manufacturers. Carbon-bonded and clay-graphite crucibles were then made by two manufacturers by standard

commercial procedures. The crucibles were sent to six different brass foundries for testing in normal use. Crucibles of both types made from domestic flake gave service equal to or even superior to that given by crucibles made from Madagascar flake.

Heindl's work is an important step toward establishing the usability of certain domestic flake graphites for crucibles. If the results are to be applied to appraisal of graphite from the two domestic mines represented, however, certain questions need answering. First, what proportion of total flake recoverable from the Alabama deposit is represented by the stockpile lot from which the test flake was prepared? Second, what proportions of the stockpile lot are represented by the test materials prepared? Similar questions arise for the graphite from the Benjamin Franklin mine, although a partial answer is given by the report (Ref. 14, p. 5) that 25 pct of the product of experimental mining and milling at the mine during 1953 and 1954 was +50-mesh flake, suitable for crucible flake.

An attempt to apply test results to domestic resources as a group is further hampered by the fact that only a few domestic flake graphite deposits have been worked at all during the last 20 years. Graphite available for testing during this period has therefore come from only a small fraction of the total number of domestic mines.

Much work therefore remains to be done before the potentialities of domestic deposits can be assessed. For any given deposit, a full investigation requires progressive adjustment of mill flowsheet combined with commercial testing of products and with research aimed at adapting current manufacturing processes to the products. Adequate testing is costly relative to possible economic returns and is a difficult undertaking for operators of a small and marginal industry.

In the crucible field, development of the carbon-bonded crucible and its increasing use in nonferrous metallurgy have introduced a new element into the graphite supply problem. This type of crucible requires, at most, no more than the amount of graphite necessary for the clay-graphite crucible, and the graphite used need not be so coarse. Furthermore, carbon-bonded crucibles were first manufactured commercially from flake graphite produced from an Alabama deposit, and Madagascar flake was used only when flake from this deposit became unavailable. At the present time, carbon-bonded crucibles are manufactured largely from Madagascar flake, and manufacturing processes are mostly adjusted to its use. There is good reason to suppose that use of domestic flake could be resumed if necessary, but a period of trial and adjustment of manufacturing processes would be involved.

Usability of domestic flake for lubricants and packing is likewise a problem. Importers of Madagascar graphite have been able to assure the consumer of a steady supply of graphite products meeting rigid specifications. The domestic producer is faced with a long uphill struggle to obtain a share of the market, and only one has thus far made substantial progress. To be successful the producer must convince the consumers that he will continue to produce graphite over a period of years, and unless he can persuade the consumer to change specifications, his products must meet specifications drawn up with reference to graphite from another source. He has another problem, and a serious one, in meeting competition on a cost basis. In addition,

it appears likely that no one graphite deposit is capable of supplying all types of lubricant and packing grade graphite. Importers have overcome this difficulty by drawing on graphites from various Madagascar mines and by blending them when necessary. The domestic operator mining a single deposit is unable to do this, and his market may be correspondingly restricted. Industry has been slow to accept domestic graphite for lubricant and packing purposes, but again, only a program combining progressive adjustment of mill flowsheets, testing in use, and research on manufacturing processes can determine the full potentialities of domestic deposits as producers of lubricant and packing grade flake.

#### National Policy for Graphite

**General Statement:** The considerations discussed above have a bearing on national policy for graphite. The cardinal objective of national mineral policy in times of emergency or international tension is assurance that the minerals required by industry will be forthcoming during the entire period of uncertainty. Solutions commonly adopted toward this end are well known: 1) measures to increase domestic production, 2) stockpiling, and 3) conservation in use. Along with these measures, steps may be taken to develop alternative sources in countries nearer at hand and less likely to be cut off from the U. S. than those that are the normal sources of supply. To some extent all these practices can be applied to graphite. The foregoing discussion indicates, however, that graphite presents special difficulties.

**Increase in Domestic Production:** As domestic resources of flake graphite are both large and readily mineable, production from them could be increased rapidly to a very high level. Until it is known, however, how much of the requisite grades of flake can be produced from domestic deposits, measures aimed only at stimulating domestic production are of doubtful value. Furthermore, figures showing increases of production may create a false impression of security. The first question to be answered for graphite concerns usability, and except as this becomes known for individual deposits, it is not possible to predict how much an increase of production will help solve the graphite supply problem.

Increase of production without regard to usability can only damage the prospects of the domestic graphite industry in the long run, for however great its short-term attractiveness, this is tantamount to a guarantee of instability. A domestic graphite mining industry can become firmly established in this country only by improving its methods of milling graphite, by adapting its products to industry needs, and by demonstrating its ability to supply these products on a continuing basis at competitive prices.

**Stockpiling:** These considerations have entered into the question of stockpiling, for it is essential that material purchased for the stockpile shall be usable by industry when needed, and in 1950, when stockpiling specifications were being reviewed, contrary opinions were held concerning the ultimate usefulness of certain source materials. One view was that all requisite grades of flake graphite could be produced from Madagascar flake, at a cost much below that of domestic graphite. According to this view Madagascar flake of the higher qualities could be purchased and stockpiled without further processing. Various types of graphite needed by indus-

try could thus be reduced to their simplest and most flexible form, because from a very few types of flake any desired grade of flake could be made.

Domestic products do not include much coarse flake; hence the policy outlined above would have excluded almost all domestic flake graphite from the stockpile. Domestic producers, on the contrary, maintained that commercial flake of numerous grades could be produced from domestic deposits. This view prevailed, and in 1950 separate specifications were written for crucible flake and for five types of lubricant and packing grade flake. Subsequent purchases of domestic graphite for stockpile were made under these specifications.

Opinions differed, however, as to how much of the domestic flake then in stockpile was usable for crucibles, lubricants, and packing. The fundamental reason for this uncertainty, which still exists, is that quantitative tests covering the properties of natural graphite have not yet been developed sufficiently to permit laboratory evaluation of the commercial usability of a particular graphite. Progress toward this end has been made through recent investigations by Mackles and others<sup>10</sup> and by Heindl and Mohler,<sup>11</sup> but the proof of usability of any given graphite still rests on successful use in history.

**Conservation:** Graphite presumably could be conserved by eliminating unnecessary use of the strategic grades and by devising substitutes. The writer is not competent to discuss this matter fully but is aware of several possibilities. Most conspicuous is the saving of coarse flake graphite that results when the carbon-bonded crucible is substituted for the traditional clay-graphite crucible. Related to conservation is the problem of simplification. It seems likely that the number of specifications for graphite current in industry is unnecessarily large and that many specifications could be eliminated. This would simplify procurement in time of emergency.

**Possible Solutions of the Graphite Problem:** The procedure indicated for dealing with the graphite problem in any emergency must depend to a large extent on whether a short emergency or a long one is envisioned. For a short emergency, the cheapest solution of the graphite supply problem is the accumulation of adequate stockpiles of Ceylon-type graphite and Madagascar flake graphite. This is also the only means of assuring supplies of all the types of graphite that industry has been accustomed to using. For this reason, any program to increase supplies of strategic grades quickly must include measures that will increase the flow of these grades from their sources abroad.

As long as adequate supplies can be had from abroad, no further action is necessary for a brief emergency. For prolonged emergency, however, it is axiomatic that the best insurance against cutoff of supplies from abroad is a productive domestic mining industry. This is true for graphite no less than for other minerals. The question is, what action would be effective in establishing a domestic industry capable of supplying the strategic grades of graphite?

Successful efforts by domestic operators to establish their deposits as sources of strategic grades would obviously offer the most satisfactory solution, and it is encouraging that one domestic operator reports significant progress toward this end. The alternative, a government program, would involve strategic and other factors outside the scope of this article. The present study indicates, how-

ever, that an effective program would have to be based on a fuller knowledge of the potentialities of domestic graphite deposits. The following information would be pertinent:

- 1) Usability of the various types of domestic graphite products currently available, as indicated by data covering past and present use and by supplementary commercial testing.
- 2) Types of graphite products recoverable on a commercial scale from different domestic deposits, by appropriate adjustment of mining procedures and milling techniques.
- 3) Possible uses of each of these products in terms of present manufacturing processes, as determined by commercial tests.
- 4) Adjustments of manufacturing processes that would lead to the most effective use of domestic graphite.
- 5) Means of increasing or achieving production, according to need, of those types of domestic graphite found to be usable.
- 6) More geologic information for detailed estimates of tonnage and grade of domestic deposits found capable of producing strategic graphite.

Any program aimed at obtaining comprehensive information on these points would involve large expenditures and would require years for completion. As long as the present ample supplies from abroad are available, a program of the kind outlined above is hardly justifiable at public expense. However, if the availability of graphite supplies beyond the period covered by stockpiles becomes doubtful, or if supplies from abroad become inadequate, appraisal of domestic graphite deposits in these respects may be a necessity. The time factor will then be important. Measures will have to be taken well in advance of needs, so that significant production rates can be attained during the life of stockpiles and so that substitution of domestic for imported graphite can be accomplished with a minimum of dislocation in the consuming industries.

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# Underclay Squeezes in Coal Mines

*A preliminary report on the mechanism of squeezes in a "dry" mine without the action of additional moisture.*

by W. Arthur White

**U**NDERCLAY squeeze is the plastic flowing of underclay below coal pillars into mined-out entries and rooms. Squeezes may be caused either by wet mine conditions where the moisture is taken up by the clay—making it more plastic—or by the presence of certain clay minerals, such as montmorillonite, which are plastic when there is enough natural moisture. Under either condition, sufficient stress will cause the underclay to flow.

Squeezes may fill an entry or room within several hours, or it may be several months before movement stops. Squeeze areas commonly cover hundreds or thousands of square yards.

The Coal Div. of the Illinois State Geological Survey has collected samples of underclays from various mines and from cores drilled by coal companies in the state. From these samples natural moisture content, particle size and particle size distribution, and clay mineralogy are determined. Data from samples collected from the underclay below Herrin (No. 6) coal in the Lumaghi Coal Co. mine near Collinsville, Ill., are used in this report to clarify points in the discussion. Data from samples taken from other mines lead to the same conclusions. A generalized geological section for the area is given in Table I.

The underclay below coal No. 6 ranges from a few inches to 3 or 4 ft thick. The upper 6 to 18 in. are noncalcareous; the lower part becomes more calcareous with depth. Limestone nodules become larger with depth, almost grading into the limestone below. In areas where the clay is nearly absent the limestone may thicken to take its place; thus they may complement each other in thickness.

There are two types of squeeze areas in a mine. In one type up to 3 or 4 ft of underclay lie in what appears to be a depression in the limestone underneath. This is suggested by a rim surrounding the squeeze area where the underclay is thin and the limestone lies within a few inches of the coal. In the second type the underclay of the squeeze area is surrounded by underclay of similar thicknesses which does not squeeze.

**Test Methods:** Natural moisture content, particle size and particle size distribution, and clay mineralogy were determined by the following methods:

Natural moisture is the moisture content a clay contains in its natural environment, expressed in

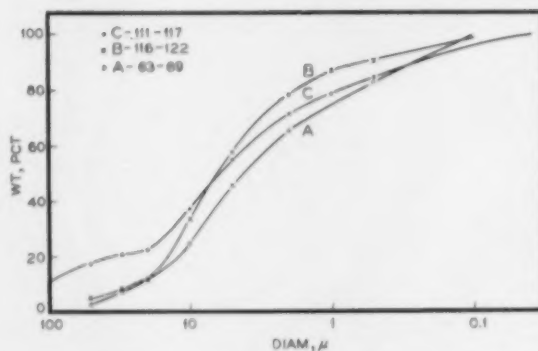


Fig. 1—Cumulative curves showing variation of particle size distribution of sample A taken from squeeze area and samples B and C taken from nonsqueeze areas.

percentage of the weight of oven-dried clay (110°C or 230°F). To obtain the natural moisture content, given in Table II, the clay samples were sealed in containers as soon as the samples were taken in the mines.

Particle size and particle size distribution were determined by the pipette method,<sup>1</sup> and the data were plotted as cumulative curves, Fig. 1, on semi-logarithmic paper. Particle size was plotted on the logarithmic scale and percentage on the arithmetic scale. The quartiles (diameters that correspond to frequencies of 25 and 75 pct) and medians (diameters that correspond to the frequency of 50 pct) of the samples were determined from these curves.

The clay minerals were identified from the data obtained by differential thermal<sup>2</sup> and X-ray powder<sup>3</sup> techniques. The differential thermal analyses were made on the whole samples, whereas the X-ray analyses were made on fractions of less than 2 $\mu$ .

## Data and Discussion

**Moisture Content:** After the sealed jars had stood for 24 hr, those that contained squeeze samples had perspired, so that droplets of water had accumulated on the insides of the jars. Table II shows the moisture in the clay after it had perspired for 24 hr. (This perspiring was not noted in samples from nonsqueeze areas.) After perspiration one of the squeeze samples still had a higher moisture content than the samples that did not squeeze.

**Clay Mineralogy:** The thermal analysis, Figs. 2 and 3, indicates that the clay minerals are chiefly micaceous in type; the low-temperature endothermal

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peak between 0° and 200°C suggests that montmorillonite is present. Pyrite, organic matter, and in some samples carbonate are indicated.

Table I. Generalized Section in Area of the Lumaghi Coal Mine

Strata	In Feet
Pleistocene undifferentiated	55±
Pennsylvanian	
Limestone	2/3±
Shale	6 1/2±
Siltstone	18±
Shale	70±
Limestone	6±
Shale	10±
Limestone	4±
Sandstone	10±
Shale	7±
Limestone	3±
Black shale	2 1/2±
Coal No. 6	7±
Underclay	3±
Clay and shale with nodular limestone concretion and benches of limestone	22±

Seven of the squeeze samples and two samples each from the nonsqueeze pits were submitted to W. F. Bradley of the X-ray Div. to obtain confirmation of the clay minerals and approximate percentages, Table III. The data indicate that montmorillonite is the dominant clay mineral in the clay fraction of the squeeze clay and that it is less abundant in nonsqueeze samples. The clay in sample C, although listed as montmorillonite and illite, is actually a mixed-lattice type of clay mineral which is a hybrid of the two, see Fig. 4.

**Particle Size Analysis:** Particle size was determined because samples studied in this laboratory have suggested that if the percentage of clay were greater than 45 pct of all materials in the sample, the clay might be unstable regardless of the clay mineral present.

Table II. Natural Moisture Content of Clay

From Squeeze Area		From Nonsqueeze Area			
Sample A		Sample B		Sample C	
Inches Below Top of Underclay	Moisture, Pct	Inches Below Top of Underclay	Moisture, Pct	Inches Below Top of Underclay	Moisture, Pct
0 to 9	7.93	0 to 6	11.33	0 to 6	10.60
9 to 15	10.73	6 to 12	8.64	6 to 12	11.01
15 to 21	12.44	12 to 18	9.36	12 to 18	11.54
21 to 27	10.60	18 to 24	9.73	18 to 24	9.55
27 to 33	8.07	24 to 30	9.83	24 to 30	5.99
33 to 39	8.55	30 to 36	9.38		
39 to 45	8.49				
45 to 51	7.17				
51 to 55 1/2	7.69				

None of the samples studied had as high as 40 pct clay size ( $2\mu$  and less) but as indicated in Tables IV and V, the particle size of the samples taken from the squeeze area is generally smaller than those taken from nonsqueeze areas. The clay fraction ranges from 20.4 to 35.1 pct clay for the squeeze area; in the nonsqueeze areas, see Table IV, the range is from 17.6 to 28.4 pct. Table V shows that the 25 pct quartile is in the clay size, but only one sample from a nonsqueeze area had more than 25 pct clay. If the underclay had had the clay minerals illite and kaolinite, or a mixture of the two, clay with these percentages would probably have been stable. Grim<sup>4</sup> has shown that montmorillonite produces a sensitive clay even where it is present in minute percentages (10 pct').

**Discussion:** Clays, shales, and soils are composed of clay minerals and nonclay minerals in variable proportions. The most abundant nonclay minerals are quartz, pyrite, and mica. Quartz and pyrite are more or less equidimensional. The clay minerals (kaolinite, illite, chlorite, and montmorillonite), on the other hand, are similar to the micas in that they may be much larger in two dimensions than in the third. Kaolinite usually has a smaller ratio between the three dimensions than the other three clay minerals. Illite and chlorite are intermediate and montmorillonite has the greatest ratio between thickness and the other two dimensions. The plate or leaf shape is responsible for the plastic properties of clays.

Table III. Percent of Clay Minerals in the Clay Fraction of the Underclay Sample

Location (Inches Below Top of Underclay)	Illite	Kaolinite	Montmorillonite	Other
<b>Sample A</b>				
0 to 9	10	10	70	10
9 to 15	10	10	70	10
15 to 21	10	10	70	10
21 to 27	20	10	50	20
27 to 33	30	10	50	10
33 to 39	10	10	70	10
39 to 45	20	10	50	20
45 to 51				
<b>Sample B*</b>				
0 to 6	20	10	50	20
6 to 12	30	10	40	20
<b>Sample C*</b>				
0 to 6	40	trace	40	20
6 to 12	50	trace	40	10

\* Samples taken for X-ray analysis were those that would probably contain the most montmorillonite as indicated by differential thermal curves.

Since montmorillonite is very thin in relation to the other two dimensions, it has considerably more surface along which slippage can take place than do the other clay minerals and thus is more plastic. Water that enters between these layers spreads them apart, sometimes one or more times the thickness of the clay mineral. As the layers of water increase between the clay particles, the clay swells and becomes more easily deformed. Grim and Cuthbert<sup>5</sup> have indicated that at atmospheric pressures calcium montmorillonite takes up a maximum of about four layers of water between the plates, which are solid, and that the fifth layer has some liquid properties. Hendricks et al.<sup>6</sup> suggest that the solid water on the surface of the montmorillonite has a hexagonal arrangement similar to that of ice.

Samples A have a large percentage of montmorillonite in the clay fraction (Table III). In Table VI the middle column gives the number of layers of water that would be held if all the water were between the montmorillonite plates, and the last column gives the number of water layers present if all the clay is treated as montmorillonite. Neither of these columns gives the correct amount of water contained between the layers; it probably lies somewhere between. If it is assumed that all the water is between the montmorillonite layers, the clay would have more than four layers of water, each being one molecule thick. In sample A 0 to 15, only one layer in ten would have five layers of water, whereas sample A 33 to 39 would have eight in every alternate layer and nine in the intermediate layers. The

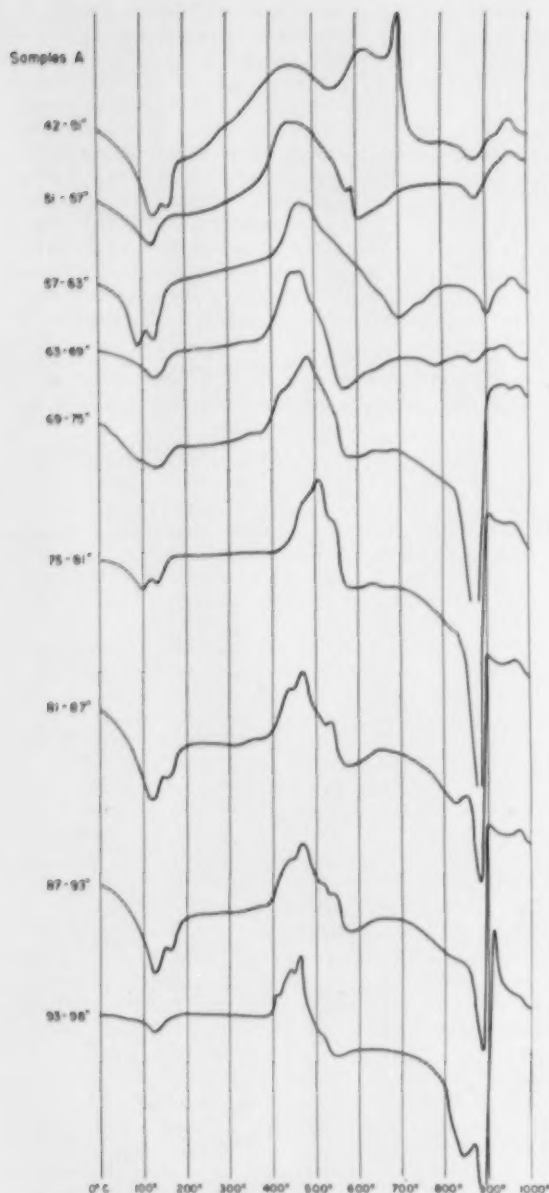


Fig. 2—Differential thermal analysis curves of samples taken from squeeze areas.

range is probably between four and six molecular layers of water.

The situation that leads to squeezing can best be visualized by an analogy with ice. Just as ice deforms and flows plastically under pressure, as in glaciers, the second and third layers of water between the montmorillonite sheets may also deform and flow under rock pressures. This is thought probable because these water layers have the structure of ice.<sup>7</sup>

To arrive at an estimate of the pressure exerted by the overlying sediments, the average densities of the rocks were estimated using Tables II through VI in the *Handbook of Physical Constants*.<sup>8</sup> The underclay was under a pressure of approximately 200 psi before the coal was removed; after 50 pct of the coal was removed, the pressure on the pillars

was increased to approximately 400 psi, which would be equivalent to about 1000 ft of ice. To return to the glacier analogy, this is about four times more pressure<sup>9</sup> than is needed to cause ice on a level plain to flow plastically under load. It would probably take more pressure to cause a glacier to move uphill; therefore, if the glacier is 250 ft thick in the center and only 3 or 4 ft thick at the edges, it would

Table IV. Percent of Clay, Silt, and Sand in Samples

Location (Inches Below Top of Underclay)	Clay <2 $\mu$	Silt 2 to 50 $\mu$	Sand >50 $\mu$
<b>Sample A</b>			
0 to 9	22.2	66.9	10.9
9 to 15	33.1	66.0	1.9
15 to 21	31.7	67.1	1.2
21 to 27	35.1	62.2	2.7
27 to 33	23.5	64.7	9.8
33 to 39	20.4	62.6	17.0
39 to 45	27.7	71.3	1.0
45 to 51	22.2	70.7	7.1
51 to 55 1/2	23.3	68.9	7.8
<b>Sample B</b>			
0 to 6	21.2	74.8	4.0
6 to 12	17.6	68.5	13.9
12 to 18	21.3	68.6	10.1
18 to 24	20.6	66.0	13.4
24 to 30	22.6	72.5	4.9
30 to 36	18.8	75.7	5.5
<b>Sample C</b>			
0 to 6	24.5	70.8	4.7
6 to 12	23.0	75.4	1.6
12 to 18	24.3	74.3	1.4
18 to 24	28.4	64.7	16.9
24 to 30 1/2	18.1	64.7	17.2

remain stationary. There is probably a point where added weight would cause the ice to flow out at the center, causing the thinner ice near the edges to crack and rise at the edges. This analogy could be applied to the underclay. The present writer's hypothesis as to the mechanism by which the underclay is squeezed from under the pillars is discussed below.

As the load was taken off the underclay between the pillars, the clay rebounded somewhat, causing the joints to open slightly. As the clay began to flow plastically (similar to creep as defined by civil engineers) from beneath the pillars it penetrated the joints in the clay, spreading them apart. As it continued to flow it shoved one block between other blocks to make room for the clay that was flowing out. As the flowing clay reached the point where pressure was released, the water between the clay particles again behaved as solid water. The moving blocks were then shoved between still other blocks, as evidenced by striations along their entire lengths. (The deep striae were caused by the limestone nodules which are in the surface of other blocks that were being bypassed or that passed over or under it during the movement.)

The rate at which squeeze takes place probably is a function of the degree of difference between the amount of pressure required to cause the underclay to fracture and rise and the pressure exerted by the overlying rocks. The pressure necessary to cause movement will depend to some extent on the amount of clay present, the kind of clay mineral, and the number of molecular layers of water between the clay particles.

Samples B and C would probably be unstable if more load were applied, but they would tend to be more stable than sample A because they contain less montmorillonite, less clay in the underclay, and more material coarser than clay.

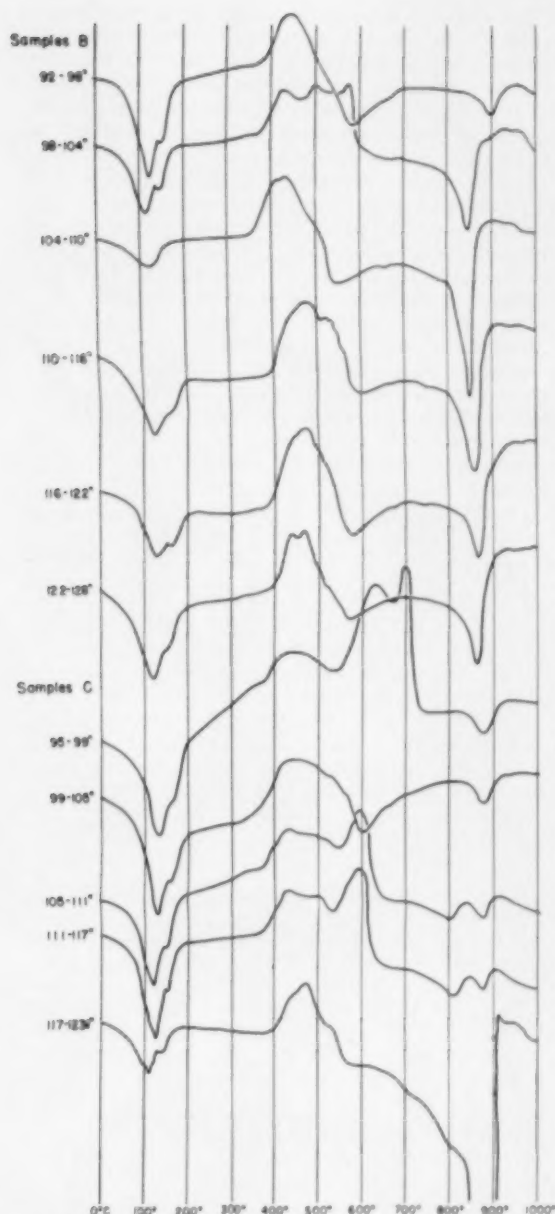


Fig. 3—Differential thermal analysis curves of samples taken from nonsqueeze areas.

The clay in sample C is probably more stable than that in sample B because the crystals of the mixed-lattice type of mineral are thicker and the clay is less plastic. The thicker crystals would have a tendency to produce more wedging or interlocking of grains than the thin montmorillonite crystals.

#### Evaluation of Clay for Control of Underclay Squeezes

To control underclay squeezes, it may be first necessary to identify the clay minerals which are most likely to become unstable when subjected to loads that are considerably greater than their consolidation load. (In the Lumgahi mine they are double the consolidation load.) Present evidence indicates that underclays high in montmorillonite are most likely to be unstable.

**Methods of Detecting Montmorillonite:** The presence of montmorillonite can be determined by sev-

eral methods. The most positive is X-ray, especially when small percentages are involved. Less reliable methods are differential thermal analysis, microscopic examination, and staining techniques. The staining method would probably be the most satisfactory for the coal industry because results can be obtained within a few minutes and the cost is low.

Table V. Quartiles and Median of Samples, Diameter in Microns

Location (Inches Below Top of Underclay)	25 Per	50 Per	75 Per
<b>Sample A</b>			
0 to 9	2.40 <sub>μ</sub>	7.95 <sub>μ</sub>	22.4 <sub>μ</sub>
9 to 15	1.27	5.65	9.25
15 to 21	1.47	3.95	9.10
21 to 27	0.99	4.40	9.90
27 to 33	2.00	6.10	12.50
33 to 39	2.45	5.95	12.20
39 to 45	1.75	4.90	11.00
45 to 51	2.30	5.95	12.50
51 to 55 1/2	2.25	6.07	13.20
<b>Sample B</b>			
0 to 6	2.50	6.68	13.40
6 to 12	3.30	8.15	18.70
12 to 18	2.60	6.65	13.40
18 to 24	2.50	7.05	15.80
24 to 30	2.35	6.17	12.50
30 to 36	3.09	6.20	12.00
<b>Sample C</b>			
0 to 6	2.03	5.20	11.70
6 to 12	2.20	5.80	12.20
12 to 18	2.05	5.87	12.50
18 to 24	1.45	5.26	16.20
24 to 30 1/2	2.70	6.00	18.50

Several stains could be used, but some will give colors for clay minerals other than montmorillonites. These stains can either be sprayed on a section of the core or dropped on some of the ground material with a medicine dropper. Mielenz, King, and Schieltz<sup>10</sup> indicate that benzidine stains only the montmorillonite clay minerals. Benzidine when added to montmorillonite gives a purple-blue color when first applied, but as the clay dries the color fades.

Table VI. Number of Water Layers That Could Occur Between Montmorillonite Plates or Sheets

Location (Inches Below Top of Underclay)	Maximum Number*	Minimum Number†
<b>Sample A</b>		
0 to 9	5.1	3.6
9 to 15	4.1	3.1
15 to 21**	5.7	4.0
21 to 27	4.3	3.0
27 to 33	6.3	3.2
33 to 39	8.4	4.2
39 to 45	4.4	3.1
45 to 51	6.5	3.2

\* Assumes that all water is between the montmorillonite layers.

† Assumes that all clay is montmorillonite.

\*\* It was assumed that this sample had as much montmorillonite as the sample above and the sample below.

Grim<sup>11</sup> states that the staining tests have been used successfully in areas where there were no other constituents that might cause or inhibit color reactions. One coal company in Illinois is using the benzidine staining test successfully at present. It must be pointed out that before the test is used in an area and the results considered reliable, the clay mineralogy of the underclay should be verified by some other means, preferably by X-ray analysis.

**Control of Squeezes:** No simple way is known to treat clays of this kind chemically in order to stabilize them, but the British<sup>12</sup> have reported some

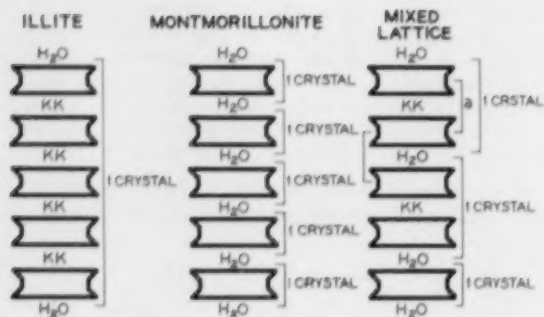


Fig. 4—The difference between a crystal of illite, crystals of montmorillonite, and crystals of a mixed clay mineral related to both illite and montmorillonite. (Crystal as used here refers to a repetition of motifs in all directions which are not changed in the presence of water.) Widths in relation to thickness have been shortened considerably. Line A of mixed-lattice clay mineral shows portion of crystals that have properties similar to montmorillonite. K = potassium and H<sub>2</sub>O = water.

success in using floor bolts to prevent underclay squeezes.

**Other Possible Values of Underclay Studies:** As more data accumulate, it may be possible to give a mining engineer information on particle size distribution, natural moisture content, and the kinds of clay minerals present in an underclay. He could then consider the sizes of the rooms, entries, and pillars the clay could stand without squeezing if the roof and coal pillars were also able to take the load and strain. This might allow more coal to be taken from some mines without hazard and eliminate squeeze troubles in others.

#### Conclusions

Squeezes take place in areas where the forces exerted by the overburden are greater than the shear resistance of the underclay.

Squeezes in dry mines probably take place in areas where the montmorillonite is most abundant and where there is a larger percentage of clay minerals in relation to the sand and silt.

The rate of squeeze is probably related to the amount of montmorillonite, load, and moisture in the clay.

At the present time there is no simple way to determine definitely where a squeeze will occur, but as data are accumulated it may be possible to give such information from a mineralogical analysis, a natural moisture determination, and a particle size distribution analysis of underclay cores before mining has started.

For dry mines that are operating, samples of underclays may be taken periodically at the face and analyzed for montmorillonite content. The analyses may show where mining is approaching an area that is likely to squeeze.

Squeezes might be controlled by floor bolting.

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## High Velocity Impact in Comminution

by R. J. Charles

PREVIOUS study<sup>1</sup> of simple impact systems indicated that energy required for fracture and size reduction of brittle materials is greatly dependent on the type of loading that is employed. In this regard it was postulated that fracture and size reduction of a brittle specimen might be accomplished by a high velocity impact at an energy level at which a low velocity impact would leave the specimen relatively undamaged. The finite time required to propagate energy away from the point of loading of an impacted object to other parts of the object and to its supports may permit a concentration of

energy at the point of impact if the rate of loading is high. Localizing of energy at the point of impact could quickly initiate fractures that would propagate through the impacted material along with the traveling stress waves. As the cracks form, the initially absorbed strain energy would be released and portions of it travel ahead of the crack tips as stress waves. These secondary stress waves, combined with the initial stress waves derived from the impact, would produce high localized strain conditions in front of the fracture zone. The fracture zone would propagate and the specimen shatter. High rates of loading are brought about by short impact times, in turn obtained by employing high velocity projectiles that are of small mass compared to the impacted object.

In the case of a low velocity impact, at an energy level equal to that of a high velocity impact that causes fracture, loading rate would be relatively

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slow and no extensive localized concentration of energy would occur. In this latter case fractures may not be initiated and the specimen might withstand the shock of impact.

The aforementioned study<sup>1</sup> also showed that for longitudinal impact of a brittle elastic bar, supported in a rigid manner, there is a specific impact time that will permit a maximum transfer of kinetic energy of impact to strain energy of the bar. This specific impact time depends on the shape of the force pulse generated by the impact. For most simple impacts, an impact time of 0.5 to 2.0 times the period of fundamental vibration of the impacted specimen will result in a transfer of energy to strain energy which is greater than for impact times outside this range. To obtain impact times as short as the period of fundamental oscillation of an impacted body, the impacting object must be of small mass compared to the mass of the impacted body. Thus high velocity impacts are again indicated if fracture is the desired result. Since strain energy is the only form of energy that can directly cause fracture, an increase in the transfer of kinetic energy to strain energy, which may be obtained by selecting specific impact times, might result in an increase in efficiency of size reduction. Unfortunately, the above relationship between energy transfer and impact times can only be shown to be valid if fracture of the impacted specimen does not occur. If fracture does take place during time of loading the energy transfer process may be modified and the effect of impact time on the overall size reduction of the specimen cannot be predicted in advance of experiment.

To verify the above hypothesis and to illustrate the effects of high velocity impacts in comminuting systems the following impact fracture tests have been made on glass specimens.

**Experimental Apparatus:** The glass specimens selected for the impact fracture experiments were pyrex cylinders 2 in. long and 1.125 in. diam. Pyrex glass was chosen, since it is relatively inert to atmospheric conditions that cause aging, is easily obtainable, deforms elastically until fracture, and behaves in many other respects like materials encountered in crushing and grinding operations. The cylinders were cut from 5-ft lengths of pyrex rod and the ends ground flat and perpendicular to the long axes ( $\pm 0.5^\circ$ ). The specimens showed no evi-

dence of residual stress when examined by a photoelastic technique.

The period of fundamental oscillation (longitudinal) of the rod specimens was calculated to be approximately  $20 \mu$  sec by means of Eq. 1.<sup>2</sup>

$$T = (4l^3 \rho / gE)^{1/3} \quad [1]$$

where  $T$  = period of oscillation in seconds;  $l$  = rod lengths, 5.08 cm;  $\rho$  = density of pyrex glass, 2.31 g per cm<sup>3</sup>;  $g$  = acceleration of gravity, 980 cm per sec<sup>2</sup>; and  $E$  = Young's Modulus of glass,  $6.93 \times 10^{10}$  g per cm<sup>2</sup>.

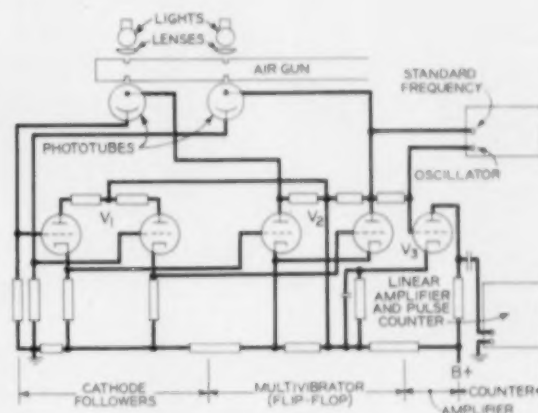


Fig. 2—Velocity measuring circuit.

Two impacting objects were used in the fracture tests. One of these was a dropping weight of mild steel weighing 3.69 kg and the other was a mild steel projectile weighing about 12 g. To preserve geometrical similarity at the point of impact a short spigot was machined on the striking end of the dropping weight to correspond to the shape of the end of the projectile. For both impacting objects the surface making contact with the glass specimens was spherical and of 6-in. radius. Figs. 1a and 1b give the dimensions of the impacting objects.

The impact time of the 12-g projectile on the glass specimens was about  $30 \mu$  sec or about 1.5 times the period of longitudinal oscillation of the specimens. This value was measured by tests wherein the projectile, when in contact during impact with the end surface of a specimen, acted as a switch which modified a timing trace on an oscilloscope.<sup>1</sup> The impact time was read directly from the oscilloscope screen. By contrast, the impact time of the dropping weight was of the order of milliseconds rather than microseconds.

The fracture tests were made at a number of levels of kinetic energy of impact and thus the velocities of the dropping weight and the projectile

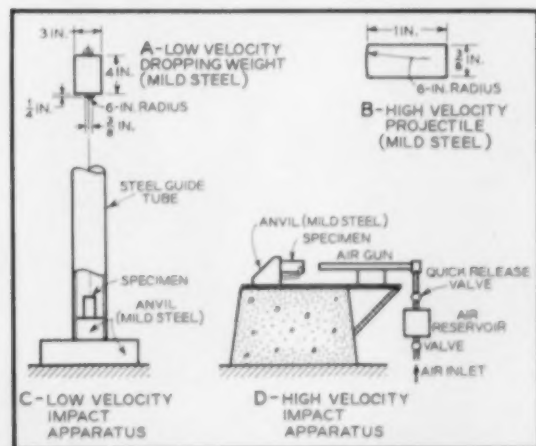


Fig. 1—Equipment for high and low velocity impacts on glass specimens.

Table 1. Impact Fracture Tests

Impact Energy, Kg-Cm	Impact with 3.69 Kg. Dropping Weight	Impact with 11.9 G. High Velocity Projectile
170	All ten specimens fractured	All ten specimens fractured
140	Eight out of ten specimens fractured	All ten specimens fractured
110	Three out of ten specimens fractured	All ten specimens fractured
80	Two out of ten specimens fractured	All ten specimens fractured
50	No specimens fractured	All ten specimens fractured

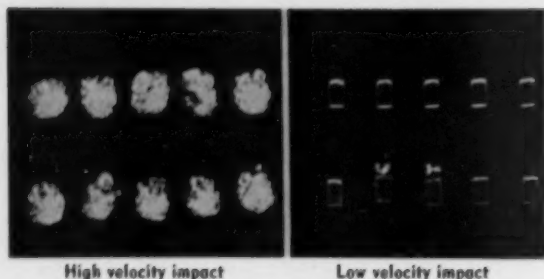


Fig. 3—Results of fracture tests on glass specimens with high and low velocity impacts. Impact energy: 50 kg-cm.

just prior to impact for any specific energy level were adjusted to conform with Eq. 2.

Kinetic energy of impact =  $Mgh$

$$= \frac{1}{2} MV^2 = \frac{1}{2} mv^2 \quad [2]$$

where  $M$  = mass of dropping weight;  $V$  = velocity of dropping weight prior to impact;  $m$  = mass of projectile;  $v$  = velocity of projectile prior to impact; and  $h$  = height of fall of dropping weight.

The dropping weight impact apparatus consisted of a steel tube that guided the weight to the specimen and a heavy steel anvil on which the specimen was placed. Energy of impact was determined by measuring the height of fall of the weight. Fig. 1C illustrates this apparatus.

The projectile impact apparatus consisted of an air gun and a heavy steel anvil. The air gun was calibrated with a velocity measuring device so that for a specific barrel length and projectile weight a known pressure would result in a known exit velocity of the projectile from the barrel. Fig. 1D illustrates the air gun apparatus. An electronic device consisting of phototubes, slits, and light sources was used to measure velocities of the projectiles. A simplified circuit for the velocity measuring device is given in Fig. 2.

**Experimental Results:** Table I shows the results of fracture tests on the glass specimens at a number of levels of impact energy. Low velocity impact tests at an impact energy of 50 kg-cm did not result in fracture of any of the specimens, whereas high velocity impacts at the same energy level resulted in fracture of all the specimens tested. It was necessary to raise the level of impact energy at low velocity to 170 kg-cm before fracture of all specimens occurred.

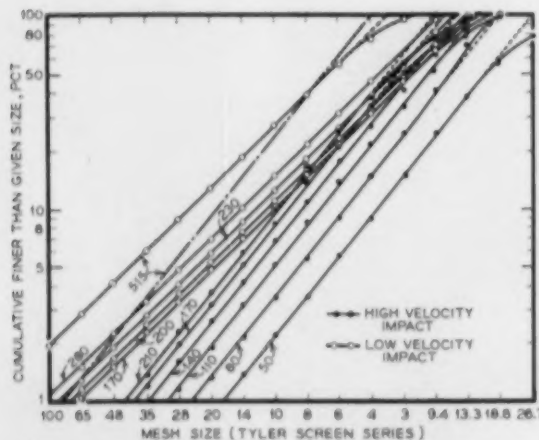


Fig. 4—Size distributions of fractured glass specimens as a function of impact energy (kilogram-centimeters).

Fig. 3 illustrates some of the products from the impact tests at the low energy value of 50 kg-cm and shows the high degree of shattering obtained with the high velocity impacts and the relatively undamaged low velocity impact specimens.

In Fig. 4 the logarithm of the percent cumulative finer than a given size is plotted vs the logarithm of that size. Crushed homogeneous materials generally show a straight line size distribution relationship when plotted in the above manner. Such a relationship indicates that the ratio of weights of material recovered on successive screens is constant if the size of successive screen apertures varies in a geometric progression, e.g., Tyler screen series. Since pyrex glass is considered to be a homogeneous material, straight line size distribution plots would be expected and the experimental results, as illustrated in Fig. 4, show this to be the case for all types of impact crushing investigated.

It will be seen that increases of impact energies in the high velocity shattering experiments resulted in a shift of size distribution lines to positions parallel to the lowest energy line and in the direction of increasing fineness of product. Since the slopes of the size distribution lines remain constant under all values of impact energy at high velocity the ratio of weights of material recovered on successive screens is also constant with respect to energy of impact. These results indicate that the energy of input to the system by a constant weight projectile does not affect the mode of fracture of the specimens but only determines the amount of fracture or size reduction that is obtained.

Increases in energy input at low velocity also produce size distribution lines that are parallel to that of the lowest impact energy line and shifted in the direction of increased fineness of product.

The slope of the size distribution lines for the low velocity impacts, however, is considerably less than that of the size distribution lines for the high velocity experiments. From the graph, Fig. 4, the slope for the former case is about 1.1, whereas in the latter case the slope is about 1.4. Since different slopes indicate different modes of fracture it may be concluded from the results of the two types of impact that the mode of fracture is dependent on the mass of the impacting object and not on the impact velocity or the total impact energy.

It was of considerable interest to the author to note the high value of 1.4 for the slope of the size distribution lines for the products from the high velocity impacts. As clearly shown in Fig. 4, a high value for the slope of the distribution line of a crushed product indicates a close sizing. In the usual methods of crushing and grinding a slope value of 1.1 is rarely exceeded and a value as high as 1.4 is abnormal. The phenomena is of practical interest, since crushing and grinding between narrow size limits is a problem of great industrial importance.

Inspection of the size distribution lines in Fig. 4 does not permit a simple conclusion as to whether or not high or low velocity impacts are more satisfactory for size reduction of the glass specimens. Obviously the high velocity impacts cause more size reduction up to an energy level of 170 kg-cm since no consistent fracture takes place with low velocity impacts at energies below this value. At 170 kg-cm the size distribution lines for high and low impact velocity cross one another below the 50 pct point, thus preventing a conclusion as to whether high or low velocity impacts result in a greater size reduc-

tion. The size distributions fit the Schuhmann equation<sup>6</sup> as follows:

$$y = 100(x/k)^m \quad [3]$$

where  $y$  = percent cumulative finer than a size;  $x$  = particle size;  $k$  = size modulus (value of  $x$  when  $y = 100$ ); and  $m$  = a constant. It may be seen that for assemblies of particles that follow Eq. 3, values for  $m$  and  $k$  completely specify a particular size distribution. If  $m$  is constant for a special group of particle assemblies then the value  $k$  alone completely specifies a size distribution. For constant  $m$ ,  $k$  is a measure of the size reduction obtained in a comminuting process and is termed the size modulus. For the impact tests in this investigation the size moduli have been plotted in Fig. 5 vs impact energy on log-log paper. For both types of impact a straight line results. The slope of the log  $E$  vs log  $k$  line for low velocity impact, curve A in Fig. 5, is  $-1.07$ , whereas the corresponding slope for the high velocity impact, curve B in Fig. 5, is  $-1.38$ . Thus for an  $n$ -fold change in impact energy the change in size modulus for the low velocity impact is greater than that for the high velocity impact. By extrapolation the  $k$  value for a high velocity impact of 515 kg-cm energy would be 4.6 mm. Using this  $k$  value the size distribution line for a high velocity impact of 515 kg-cm has been plotted, as a dashed line, in Fig. 4. This line may be compared with the experimental line for low velocity impact at the same energy. It is apparent that at this energy the low velocity impact produces a greater size reduction than the high velocity impact even though the size reductions at the energy value of 170 kg-cm may be roughly equivalent. Consequently it would appear that, if fracture takes place, low velocity impacts may cause

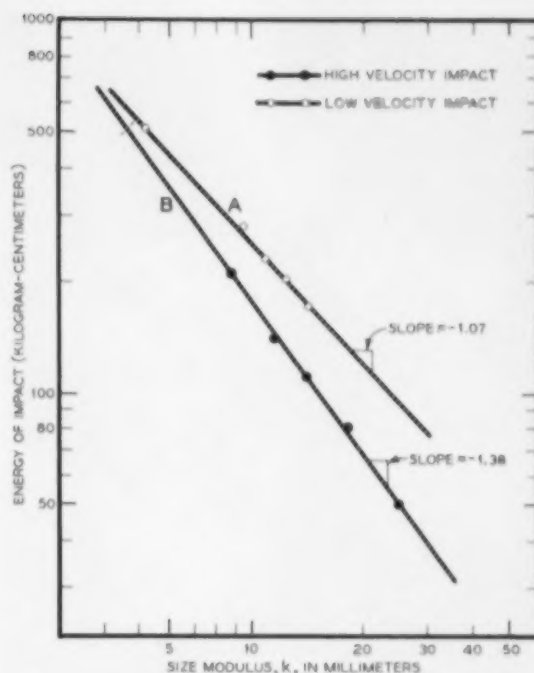


Fig. 5—Impact energy vs size modulus for fractured glass specimens.

a greater size reduction than high velocity impacts.

To explain these results in the light of the experiments on energy transfer as outlined in the introduction it must be concluded that fracture occurs during loading time and restricts the energy transfer process to such extent that proportionally less energy is absorbed before fracture by high velocity impact than by low velocity impact. High velocity impacts are useful for initiating fractures and for obtaining closely sized products, but for overall size reduction the low velocity impacts may be more efficient.

During the course of the fracture experiments it was noted that the characteristic shapes of the pieces of glass from the specimens ruptured by impact at low velocity with the dropping weight were very different from those of the specimens ruptured by the high velocity projectiles. For the former the fractured particles were most commonly in the form of splinters and needles. Examination of sized fractions of these particles showed that the splinter or needle structure persisted even to fine sizes (100 mesh). It was also observed that very little internal fracture occurred within the particles that resulted from rupture. In the case of the high velocity impacts the particles resulting from rupture were blocky and equidimensional and showed appreciable internal rupture. The typical needle-like structure of low velocity rupture was not evident in any of the size ranges down to 100 mesh. Fig. 6, showing a few of the screened fractions of the fractured specimens, illustrates the difference in particle shape.

From shapes of pieces resulting from the fracture tests it was concluded that the fracture mechanism and pattern were different, and it was postulated that the low velocity impact tests acted in much the same manner as slow compression tests of glass blocks.<sup>6</sup> Radial tensions were produced by slow end loading and the specimens ruptured mainly by

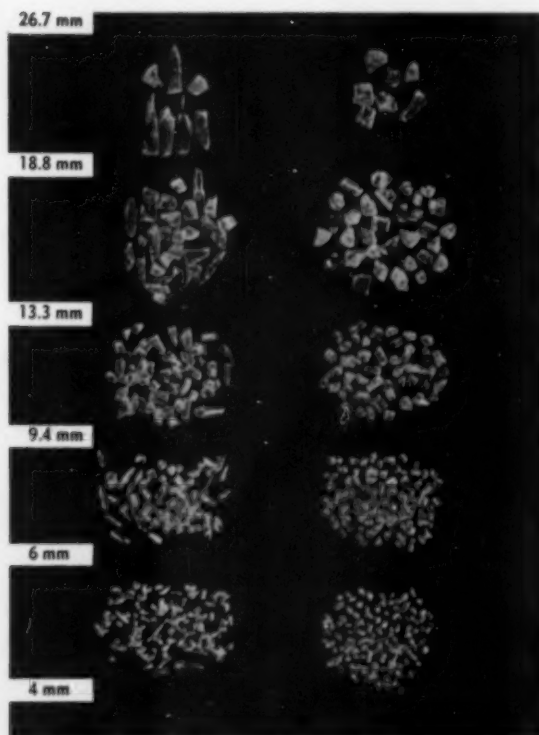


Fig. 6—Screened fractions of fractured glass specimens. Impact energy: 170 kg-cm. Right-hand column, low velocity impact; left-hand column, high velocity impact.

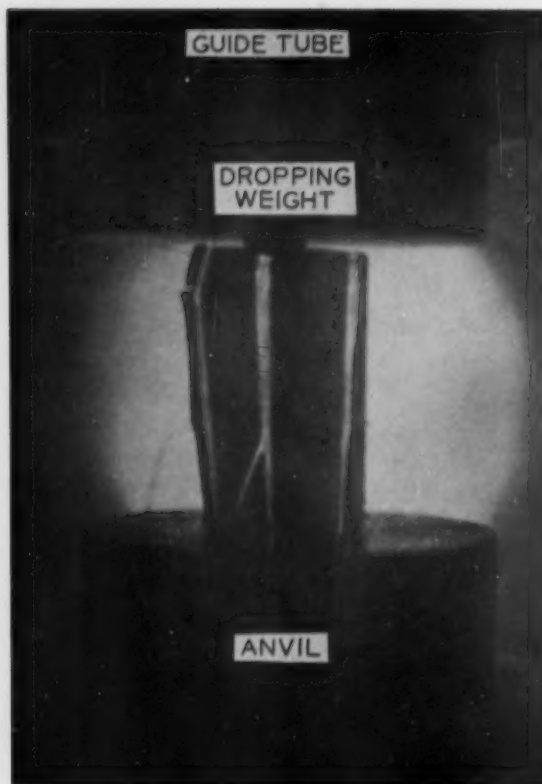


Fig. 7—High speed photograph of glass cylinder impacted at low velocity.

longitudinal cracks parallel to the direction of load. No abrupt changes in stress occurred within the specimen before fracture and the cracks, upon initiating, travelled in relatively straight lines. Some cross fractures developed and shortened the splinters, but the longitudinal direction of fracture propagation was predominant. On the other hand, the high velocity impacts produced extensive interaction of stress waves coupled with some form of the stress conditions produced by slow loading, and resulting fractures were randomly oriented in the direction of propagation. The particles produced in the latter case were irregular and blocky and were subject to considerable internal fracture.

To investigate the fracture processes in the impact tests more closely short exposure photographs



Fig. 8—High speed photograph of glass cylinder impacted at high velocity.

were made of the fracture patterns on the surface of the specimens just prior to the instant when the ruptured pieces flew apart. The light source for the photographs, a General Radio Stroboscope, permitted exposures of the order of  $20 \mu$  sec. A silver conducting strip was painted on each of the specimens and connected to an electronic switch, so that when the strip was severed by a crack in the specimen the stroboscope was tripped and a photograph obtained.

Figs. 7 and 8, obtained in this manner, show the specimens in a state of partial fracture prior to explosive disintegration. In Fig. 7 straight longitudinal cracks are caused by the low velocity impact of the dropping weight. The specimen is shown to break up much like a piece of cord wood being split by an axe. In Fig. 8 the fractures form a complex network consisting of a few longitudinal cracks leading from the point of impact and a larger number of branching vein-like cracks stemming from a major crack starting from the fixed end of the specimen. Figs. 7 and 8 clearly show that two dissimilar modes of fracture occurred and illustrate the process by which particles of different characteristic shape were produced.

### Conclusions

The following conclusions may be made from the experimental results of this investigation.

1) High velocity impact may bring about fracture of a brittle object at an energy considerably less than that required to fracture the object at low velocity impact.

2) When fracture of a brittle object is obtained, energy applied by low velocity impact or slow compression loading may produce a larger size reduction of the specimen than an equivalent amount of energy applied by high velocity impact.

3) The mode of fracture of a specimen of a homogeneous material is determined by the manner in which the loading forces are applied and not by the amount of energy available. As a corollary to this conclusion it may be stated that, for a single material, different methods of applying impact loads will produce different characteristic particle shapes and different types of size distributions.

4) Shattering by high velocity impact produces a closer sized product than shattering by low velocity impact.

### Acknowledgments

The author wishes to acknowledge the assistance given him by his associates at the Massachusetts Institute of Technology and especially thanks A. M. Gaudin for his suggestions and interest in the investigation.

The work was carried out under the Comminution Research Program of the Department of Metallurgy at Massachusetts Institute of Technology. Initial sponsorship was received from the Engineering Foundation. The current program is sponsored by the Engineering Foundation, the American Iron and Steel Institute, the U. S. Atomic Energy Commission, Aerofall Mills, Allis-Chalmers Mfg. Co., Bethlehem Steel Co., Kennecott Copper Corp., National Gypsum Co. and Union Carbide & Carbon Corp.

### References

- <sup>1</sup> R. J. Charles and P. L. de Bruyn: Energy Transfer by Impact. *AIME Trans.*, vol. 205, pp. 47-53.
- <sup>2</sup> S. Timoshenko: *Vibration Problems in Engineering*. D. Van Nostrand Co. Inc., 1937, p. 308.
- <sup>3</sup> R. Schuhmann, Jr.: Principles of Comminution I. Size Distribution and Surface Calculations. *AIME T.P.* 1189, July 1940.
- <sup>4</sup> E. F. Poncelet: Fracture and Comminution of Brittle Solids. *AIME Trans.*, 1946, vol. 169, p. 37.



# aime news

Set Your Sights on Hershey

## Northeastern Mining Branch Conference

Hotel Hershey, Hershey, Pa. November 8-10, 1956

Those attending the Northeastern Mining Branch Conference in November can look forward to a well balanced technical program, interspersed with field trips, social events, and a golf tournament. The technical sessions will cover mining, geology, geophysics, industrial minerals, and concentration. Among the field trips scheduled is a visit to the charcoal furnace which dates back to 1743. The complete conference program appears in September MINING ENGINEERING, pp. 933-934.

### Hershey—Advance Reservations

Write To:

R. L. Sleeman, Treasurer  
Northeastern Mining Branch Conference  
c/o AIME  
29 West 39th Street  
New York 18, N. Y.

Registration Fees: Members—\$3.00; Nonmembers—\$5.00  
Make checks payable to R. L. Sleeman, Treas.

### ANNUAL MEETING

*Plans for the 1957 AIME Annual Meeting are progressing nicely. Scheduled for February 24-28, at the Roosevelt and Jung Hotels in New Orleans, the meeting will feature technical sessions and symposiums as well as luncheons and a banquet. Members who plan to attend should make arrangements early. See page 836A, August MINING ENGINEERING for details and registration blank.*



St. Louis Cathedral, built in 1794, is a landmark in picturesque New Orleans.

### Pittsburgh Section Holds Annual Meeting November

The Pittsburgh Section AIME, in cooperation with the Engineers' Society of Western Pennsylvania, will hold its Eleventh Annual Off-the-Record Meeting on November 2 at the Penn Sheraton Hotel, Pittsburgh. Also participating are the Coal Division, Petroleum Subsection, Institute of Metals Group, National Open Hearth Committee and Minerals and Metals Economic Committee.

General chairmen of the meeting are W. D. Doty, U. S. Steel Corp., and W. O. Philbrook, Carnegie Institute of Technology, with D. H. Davis, Mathies Coal Co., vice chairman.

Of particular interest to readers of MINING ENGINEERING will be the sessions on coal and those on mineral and metal economics. Other sessions are scheduled by the National Open Hearth Committee, Acid Open Hearth, Petroleum Subsection, and Institute of Metals Group. See page 1034 for complete program.

### Fuel Conference in Capital

The 19th Annual Joint Solid Fuels Conference is scheduled for October 25-26 in the Sheraton Park Hotel, Washington, D. C. Co-sponsored by the Coal Division of AIME, and the Fuels Division of ASME, the conference will explore the future role of solid fuels in an expanding economy. LeRoy F. Deming, ASME, is General Chairman and Louis C. McCabe, AIME, is Co-Chairman. Program appears on pages 1034-1035.

### Membership Award

In order to give greater recognition to members who have gone all-out by securing 50 membership applications, a special award has been designed.

The award will be a 14kt gold tie clasp utilizing the present design of the pin awards.

As of this time, two members are eligible for the award, Cloyd Henline and Robert Moscrip, III.

Mr. Carl Reistle, Jr., president of AIME, will present these awards at the all-AIME session in New Orleans on Tuesday, February 26.

It is fervently hoped that the gentlemen will be in attendance and that others shall join their ranks as the Annual Meeting approaches.

### Engineering Foundation Grants Research Funds

The following cash grants have been approved by the AIME Committee on Research and the Engineering Foundation for research studies, in the year ending Sept. 30, 1957: J. L. Gregg, *Alloys of Iron Research*—\$5,000; V. Paschkis, *Heat Flow in Quenching*—\$2,000; Morris Cohen, *Diffusion in Steel*—\$2,500; D. W. Fuerstenau, *Comminution*—\$2,000; R. M. Burns, *Corrosion Research Council*—\$3,000; M. Simnad, *Surface Diffusion of Metals*—\$3,000; A. M. Gaudin, *Thickening and Thickeners*—\$2,500; A. W. Huff, *Effect of Strain Waves in Blasting*—\$1,500; William L. Donn, *Storm Surges*—\$2,000.

# Pittsburgh Section Off-The-Record Meeting

## PROGRAM

### Coal Division

Morning Session 9:30 am

**Co-Chairmen:** H. C. Rose, Pittsburgh Coal Co., and J. A. Brookes, Mather Collieries

1. *Application of AC Power Underground*  
Chester Conrad, Consolidation Coal Co., Monongah, W. Va.
2. *AC Power Distribution Inside for DC Conversion Units*  
J. A. Dunn, Island Creek Coal Co., Holden, W. Va.
3. *Power Requirements for Continuous Miners*  
R. M. Hunter, Rochester & Pittsburgh Coal Co., Indiana, Pa.

Luncheon 12:30 pm

Afternoon Session 2 pm

**Co-Chairmen:** W. E. Hess, Jones & Laughlin Steel Corp., and R. L. Llewellyn, Eastern Gas & Fuel Associates

1. *Major Problems in Total Coal Cleaning*  
D. H. Davis, Mathies Coal Co., Finleyville, Pa.
2. *Mechanical and Thermal-Drying and Air Scrubbing*  
Thomas Durbin, Hanna Coal Co., St. Clairsville, Ohio.
3. *Water Clarification*  
J. J. Reilly, Jones & Laughlin Steel Corp., LaBell, Pa.

### Minerals and Metals Economic Committee

Morning Session 9:30 am

**Chairman:** H. A. Franke, Aluminum Co. of America

1. *Synthetic Nonmetallic Minerals*  
H. R. Shell, Electrochemical Lab., Bureau of Mines, Norris, Tenn.
2. *Use of Nonmetallic Minerals by Industry*  
R. D. Thomson, Div. of Mineral Industries, Bureau of Mines, Pittsburgh.
3. *New Processes in Steel Making*  
D. F. McBride, U. S. Steel Corp., Pittsburgh.
4. *Description of the Columbia Falls, Montana, Aluminum Reduction Plant, Anaconda Aluminum Co.*  
J. F. Smith, Anaconda Aluminum Co.

Luncheon 12:30 pm

Afternoon Session 2 pm

**Chairman:** C. F. McCabe, Carnegie Institute of Technology

1. *Problems in Abatement of Metallurgical Fume*  
Richard Engdahl, Battelle Memorial Institute.
2. *Recent Developments in Extractive Metallurgy*  
F. W. Coffey, Battelle Institute.
3. *Economic Consideration in Liquid Waste Disposal*  
McCloyd Snauley, Battelle Institute.
4. *SO<sub>2</sub> Distribution in Flash and Fluid Roaster Gases*  
R. G. Redelfs, St. Joseph Lead Co., Monaca, Pa.

Suppliers' Cocktail Party 5:45 pm

Fellowship Dinner 7 pm

Toastmaster: N. K. Flint

Presentation: F. L. Toy Award

Student Prize Paper Award

Dinner Speaker: Perry E. Gresham, president, Bethany College

# Joint Solid Fuels Conference — Washington, D. C.

## PROGRAM

THURSDAY, OCTOBER 25

10:00 am, Continental Room

### Technical Session I

W. S. Major and Glynn Coryell, Co-Chairmen

1. *Determination of Heat Content of Coal by Regression Analysis (Paper No. 56-FU-4)\**  
R. L. Pasek, Northwestern University School of Commerce, Evanston, Ill., and R. M. Lundberg, Commonwealth Edison Co., Chicago.
2. *Impact of Atomic Energy on Fossil Fuels*  
R. C. Dalzell, AEC, Washington, D. C. and Harry Perry, USBM, Washington, D. C.
3. *Industrial Fuel Utilization in the United Kingdom (Paper No. 56-FU-3)\**  
W. A. Macfarlane, The National Industrial Fuel Efficiency Service, London, Eng.

12:30 pm—Luncheon Meeting, Burgundy Room

L. C. McCabe, Chairman

**Speaker:** Frank W. Miller, Vice President, Region III, ASME

2:00 pm, Continental Room

### Technical Session II

A. C. Fieldner and Cloyd M. Smith, Co-Chairmen

1. *Government Development and Research Activity in Solid Fuels*  
T. Reed Scollon and Harry Perry, USBM, Washington, D. C.
2. *Underground Coal Gasification*  
C. A. Masterman, British Ministry of Fuel & Power, London.
3. *Coal Industry Research*  
Harold J. Rose and James R. Garvey, Bituminous Coal Research Inc., Columbus, Ohio.

4:00 pm, Mural Room

**Executive Committee, Fuels Div., ASME**

4:00 pm, Madison Suite

**Executive Committee, Coal Div., AIME**

5:00 pm, Mural Room

**Joint Conference Committee Meeting**

6 pm—Cocktail Hour, Caribar Room

7 pm—Banquet, Burgundy Room

LeRoy F. Deming, Chairman

(Continued on page 1035)

(Continued from page 1034)

**Toastmaster:** S. L. Jewell, Southern Coals Inc., Chicago

**Entertainment:** U. S. Navy Sea Chanters directed by Warrant Officer Harold Fultz

Presentation of Percy Nicholls Award for 1956

Presented by J. B. Morrow to Chester A. Reed.

**Speaker:** Felix E. Wormser, Assistant Secretary, Mineral Resources, Dept. of the Interior, Washington, D. C.

FRIDAY, OCTOBER 26

9:30 am, Continental Room

### Technical Session III

John F. Barkley and Herbert G. Bryan, Co-Chairmen

1. *Fly-ash Refracting* (Paper No. 56-FU-1)\*  
W. W. Maull, Public Service Electric & Gas Co., Newark, N. J.
2. A Combustion Symposium
  - a. *Ignitability Testing as a Measure of the Burning Characteristics of Solid Fuels* (Paper No. 56-FU-2)\*  
H. W. Nelson and J. Mason Pilcher, Battelle Memorial Institute, Columbus, Ohio.
  - b. *An Effort to Use a Laboratory Test as an Index of Combustion Performance*  
F. J. Ceely, and R. I. Wheeler, Foster Wheeler Corp., N.Y.C.
  - c. *Ignitability of Fresh Fuel and Reactivity of Residual Carbon*  
N. D. Phillips, Babcock & Wilcox Co., Alliance, Ohio.

2 pm, Continental Room

### Technical Session IV

Edward Steidle and H. B. Charnbury, Co-Chairmen

1. *Coal as Source of Power for Aluminum Industry*  
F. G. Feeley, Jr., Olin Mathieson Chemical Corp., N.Y.C.
2. *Changing Market Pattern for Solid Fuels*  
George A. Lamb, Pittsburgh Consolidated Coal Co., Pittsburgh.

### Ladies' Activities

THURSDAY, OCTOBER 25

9:00 am, Franklin Room—Coffee Hour

10:00 am—Tour of Rock Creek Park

1:00 pm—Luncheon, Normandy Farms, Md.

FRIDAY, OCTOBER 26

9:00 am, Franklin Room—Coffee Hour

9:30 am—Tour of Washington

1:00 pm—Luncheon and Fashion Show, Shoreham Hotel

4:00 pm—Tea at Pakistan Embassy

\* Papers available until August 1, 1957 from ASME Order Department, 29 West 39th Street, New York 18, N. Y. Price to ASME members 25¢; nonmembers 50¢.

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## Around the Sections



The yearly dinner-dance of the AIME San Francisco Section held recently, was graced by the presence of past and present section chairmen. Pictured above enjoying the festivities are, left to right: Secretary-Treasurer Edgar Barker; Mrs. Barker; Vice Chairman Robert Baldwin; Mrs. M. B. Gould; James Bradley, Chairman 1956-1957; Mrs. Bradley; Malcolm B. Gould, Chairman 1955-1956; and Mrs. Baldwin.

• The Upper Peninsula Section held an annual local section meeting in Ishpeming, Mich., on Saturday October 6. Arrangements for the day were made by D. Kelley Campbell, Cleveland Cliffs Iron Co., who was chairman of the program committee. Following registration at the Mather Inn, a trip was taken to Republic's open pit mine and mill, where froth flotation is used to concentrate hematite and specularite. The group then paid a visit to the pelletizing plant at Eagle Mills followed by a tour of the ore dock at Marquette.

A reception was held in the evening for Carl E. Reistle, Jr., AIME President, and Mrs. Reistle, and Dr. Grover J. Holt, AIME President-elect, and Mrs. Holt. The reception was followed by a banquet. A special feature of this meeting was the inclusion of members of the AIME Women's Auxiliary in the field trips as well as the social activities.

• The Montana Section AIME opened the 1956-57 season of activities with its second annual Columbia Falls Dinner Meeting and Plant Inspection trip on Saturday and Sunday, September 22-23. Program chairman R. G. Bowman and committeemen H. G. Satterthwaite and George Hanson arranged a dinner meeting at Club Rocco, Hungry Horse, Mont. at which Kent I. Newman spoke on *Mechanization in Aluminum Production*, and Hal W. Kanzler delivered a paper on *The Electrical Installation at Columbia Falls*.

On Sunday, September 23rd, members and their distaff companions took a guided inspection trip through the Columbia Falls plant of Anaconda Aluminum Co. During the business meeting, Clarence V. Saylor was elected chairman of the section to complete the unexpired term of Robert Van Pelt, who resigned the presidency of Montana School of Mines to assume the same position at Michigan College of Mining and Technology.

• Among the featured activities of Adirondack Section's July 28 meeting were visits to the St. Joseph Lead Mill in Gouverneur, N. Y. and the International Talc Mill at Hallsboro. Later the group repaired to the Gouverneur Country Club for dinner. An after-dinner speech on geophysical prospecting in this area was delivered by Roland F. Beers of the American Syndicate. In making arrangements for the day, Severn P. Brown pandered to athletic tastes by providing time and facilities for an afternoon circuit of the country club's fairways and greens.

• The Central New Mexico Section held its summer meeting on July 28. Chairman A. J. Thompson presided at the luncheon meeting in Shiprock which featured talks by Clyde Garman and Eugene Woodward of Kerr-McGee Oil Industries Inc. Later members and guests toured the Kerr-McGee plant. The evening dinner meeting took place at the Francois Cafe in Farmington. At the business session which followed, the section voted unanimously to award the annual prize of AIME Junior Membership to the best graduate of the New Mexico Institute of Mining & Technology. Prior to the formation of the Central New Mexico Section, this award had been made by the El Paso Metals Section. The fall meeting will take place in Socorro on November 17.

• When the St. Louis Section held their dinner-meeting in the Hotel York on September 14, the featured speaker was Frank C. Mansfield, general superintendent, Madison Div., Dow Chemical Co. Mr. Mansfield, who has practiced law and was formerly director of industrial relations for Emerson Electric & Manufacturing Co., reviewed the changes in labor relations and their impact on management and the general public.

• The Colorado Plateau Section and Colorado Minerals Beneficiation Sub-section held a joint meeting at the Hotel Denver, Glenwood Springs, Colo., on September 15. At the business meeting and technical session which began at 2 pm, the following papers were presented: *Processing Marble* by Carl Morris, *Atmospheric vs. Pressure Leaching in Alkaline Solutions* by Robert Beverly and Wayne Millsap, *The ELUEX Process* by William Charles and Harry Gardner, and *The New 13-foot Ball Mill of Climax Molybdenum Co.* by Frank Windolph. The session concluded with a panel discussion on ore dressing research laboratories moderated by F. T. Davis. A cocktail party, dinner and dance in the evening added a social flourish to the joint gathering.



*The Petrified River*, a 28 min, 16 mm sound film on the peaceful uses of uranium, is available from Modern Talking Picture Service. Union Carbide & Carbon Corp., which made this color film, is offering free loan prints for group showings to business and professional societies, service clubs, and other adult organizations. To obtain your print, write to Modern Talking Picture Service Inc., 3 East 54th St., N. Y. 22, specifying first choice of playdate and at least one alternative date.



A prospector searches for uranium ore with pick and geiger counter in this scene from the film, *The Petrified River*.

A 25 min motion picture on blasting is available from Atlas Powder Co. Entitled *We're Blasting Near You*, the color film describes precautions taken by blasters to prevent accidents and damage to private property, with special emphasis on modern safety methods which reduce the hazards of ground vibration, concussion, and flying rock. Write Explosives Development Section, Atlas Powder Co., Wilmington 99, Del. to schedule a showing or obtain additional information.



## Minnesota Section Reports Education Survey Results

The education committee of AIME's Minnesota section has issued a report on its 1956 program. Continuing a practice begun in 1952 by W. R. Van Slyke, the committee's activities were designed to stimulate and foster the interest of Minnesota high school students in mineral industry careers.

Questionnaires to determine the interest of each school in a visit from an industry representative were dispatched to 158 public and parochial high schools throughout the state. Despite the inclusion of reply forms and stamped, self-addressed envelopes, however, only 78 schools responded.

Meetings restricted to students interested in and capable of higher education were arranged at 44 schools, and packets containing data on curricula, scholarships, etc., were sent to 14 additional institutions where personal visits were impossible. The principal feature of the actual meetings was a talk given by a practicing engineer, supported by booklets and pamphlets, data on engineering schools, and demonstrations of some of the interesting operations of the industry. A total of 1,617 students attended, of which 643 were sufficiently interested to request additional information.

Despite the difficulties of making a realistic appraisal of the program's value, the committee felt that the increased percentage of students showing greater than average interest indicates some measure of success for its efforts over the years.

A recognition of the fact that the emphasis on upperclassmen and students who have already demonstrated a bent for engineering imposes a serious limitation on the program's potential effectiveness prompted the committee to recommend several new approaches. Wider use of demonstrations, movies, and supporting literature, as well as direct talks with younger students and community groups, have been suggested as means of contacting more potential mining engineers. The committee also recommended concerted efforts on the part of mining companies to encourage summer employment for interested students, and to stress more forcefully the benefits accruing from a career in the mineral industry.

The report's conclusions suggested the possible value of a full time director for its activities. Should the sponsoring mining companies deem an expanded program necessary and worthwhile, the committee recommends for their consideration a policy which would encourage better

and extended courses in science and mathematics in preparatory schools, and rewards to practicing mineral engineers which would be enticing to the younger generation.

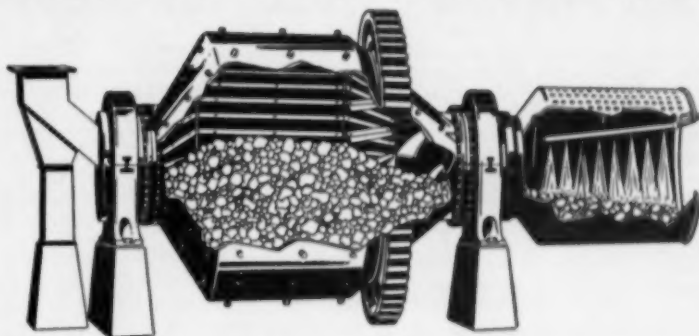
## Mudd Memorial Fund Sponsors Publications On Minerals and Rocks

The AIME Board has appropriated \$20,000 from the Seeley W. Mudd Memorial Fund for a third completely revised edition of *Industrial Minerals and Rocks*. The first edition was published in 1937 and the second in 1949. The volume, now out of print, has been one of the

most popular ever published by the Institute.

The Mudd Fund is also underwriting publication of a volume on mineral economics which it hopes to have available next year. Practically all authors of the various chapters have accepted the assignment, outlines of most of the chapters have been received, and the preliminary text of a few. Evan Just is chairman of the editorial committee for the volume and Edward H. Robie, editor. This volume will be in memory of Harvey S. Mudd and has been made possible by an additional gift to the Seeley Mudd Fund by Mr. Harvey Mudd's widow, son and daughter.

## HARDINGE SCRUBBERS FOR PIT-RUN MATERIALS

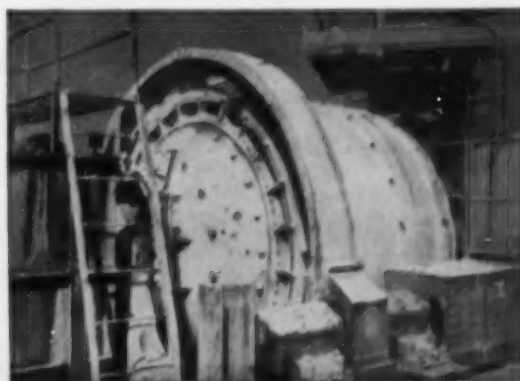


Large diameter, short length trunnions permit chute feeding of unsized ore and rock at rates up to 600 tons per hour.

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Bulletin 37-A-2

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## World Geologists Confer in Mexico

AIME delegates to the world meeting of geologists, September in Mexico City, heard discussion on atomic energy source materials. This was the first time the topic had come up at the meeting, sponsored every four years by the International Geological Congress.

Mexico's enormous mineral deposits include many nuclear resources, and the gathering featured tours of all the main mining areas. Among the symposia included were several on manganese and petroleum. Mexico also presented the results of preliminary findings in utilization of geothermic energy for production of electric power. Also emphasized at the meeting were the use of radioactive isotopes in various geological procedures. One result of the Congress will be the compilation of the first comprehensive geologic map of Mexico. One of the important papers read was by Federico Mosser of the Mexican Geological Institute, describing the transformation of the Valley of Mexico into an enclosed basin some 25,000 years ago.

Other groups represented were the Society of Mine Geologists, International Paleontological Union, and African Geological Services Assn.

## PERSONALS



M. J. ANKENY

Marling J. Ankeny was inaugurated U. S. Bureau of Mines Director on July 20, 1956, succeeding J. J. Forbes, who retired last November. Thomas H. Miller, deputy director, has been acting director in the interim. Mr. Ankeny was born in Carleton, Neb., and educated at Carnegie Institute of Technology. In 1928, he began an association with the USBM which lasted for 24 years. He left the Bureau in 1952 to become safety director for the Bituminous Coal Op-

erators' Assn., a position he occupied until his present appointment. Although widely conversant with general mining operations, Mr. Ankeny's specialty has been in inspection for mine safety. His services for the government in this capacity earned for him the Bureau's Honorary Award for Meritorious Service in 1952.

Paul Weir has been elected to honorary membership in the Institution of Mining Engineers, a federation of the eight Institutes of Mining Engineers in Great Britain. He is chairman of the board of Paul Weir Co., Chicago.



P. WEIR

Roger W. Straus will represent the primary metals industries on the advisory council of Detroit's national industrial exposition to be held October 22-26, 1956.

E. H. Greenwald has joined the firm of Eavenson, Auchmuty and Summers, consulting mining engineers, in Pittsburgh. He was formerly general manager, Boone County Coal Corp., Sharples, W. Va.

G. Keith Allen has been elected president of the British Institution of Mining and Metallurgy, located in London, for the 1957-58 term. Born and educated in Australia, Mr. Allen received the B.M.E. degree from Melbourne University in 1921. Much of his mining experience was gained in Africa, where he started in 1922 with the Rhodesia Broken Hill Development Co. Ltd. He left Africa in 1932 for the London offices of British South Africa Co. Ltd., and in 1935 became assistant consulting engineer of the West African Gold Corp. Mr. Allen was promoted to resident director and chief engineer in 1949. His service with the Institution began in 1942. He was vice president for the sessions 1946-49, and also during the current session.

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J. D. FORRESTER

**James D. Forrester** has been named successor to **Thomas G. Chapman** as dean of the College of Mines, University of Arizona, and director of the Arizona Bureau of Mines at Tucson. The new duties Dr. Forrester assumes correspond exactly with positions he has held at the University of Idaho since 1954. Holder of a B.S. degree from the University of Utah, M.S. and Ph.D. degrees from Cornell, Dr. Forrester has long been a member of the teaching profession. He taught at the University of Utah, Cornell, was professor and chairman of the geology department at the University of Idaho, and chairman of the department of mining engineering at the University of Missouri, where he also served as chairman of the committee on graduate study. His extra-academic career has included work with Anaconda Copper Mining Co., International Smelting & Refining Co., and the U. S. Geological Survey. The author of numerous articles and four texts, Dr. Forrester has also been engaged in several independent research projects since 1939. He was chairman of the MGGD Geology Subdivision, AIME; chairman of the whole division; and member of the Mining Branch Council. Dean Forrester is also a member of American Association of Petroleum Geologists, American Society for Engineering Education, and American Geological Institute.

**V. J. Southey** has left the American Metal Co. Ltd., in Newcastle, N. B., Canada, to join Dominion Wabana Ore Ltd., Newfoundland, Canada.

**Robert Devlin** is now with E. G. M. Cape & Co., Toronto, Canada. He had been mining engineer for Dominion Wabana Ore Ltd., Newfoundland.

**Bror Nordberg** has resigned as editor of *Rock Products* to become vice president of Azbe Corp., St. Louis.

**Evan Bennett** is with Banco Minero Del Peru in Lima. He had previously been a consultant in New York.

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Clarence H. Sleeman has been named chief mining and development engineer of the Ore Mines and Quarries Div., Jones & Laughlin Steel Corp., Pittsburgh. Mr. Sleeman, a graduate of Michigan College of Mining & Technology, and USAF veteran, joined the company in 1946 and was appointed assistant manager, Minnesota Ore Div. in 1954.

H. C. Livingston has been elected president of Truax-Traer Coal Co. A graduate of Colorado School of Mines, he was a director of Union Pacific Coal Co. before coming to Truax. Harry LaViers was elected a director of Truax at the same time.

B. W. Kerrigan has been appointed secretary of the Institution of Mining and Metallurgy, located in London. A student of classics, Mr. Kerrigan received his formal education at Oxford University, and terminated a teaching career in 1940 to join the R.A.F. For two years he was attached to the Marconi Co.'s Research Station, Essex. He was commissioned in the Education Branch in 1943. Following the war, he joined the staff of the Imperial College of Science and Technology and in 1953 was named chief assistant to the Director of Building Works, in which capacity he has administered much of the extensive scheme for expansion of the College.



D. HARRIS

Dwight L. Harris, formerly in the Mining and Metallurgy Dept. at the University of Wisconsin, is now research metallurgist, American Chrome, Co., Nye, Mont.

Keith Kunze has been appointed general superintendent, Getchell Mine Inc., Golconda, Nev. His former position of mill superintendent will be filled by Edward Buchanan. Other Getchell appointments are Thomas Q. Morris, chief engineer, and Mike Evasovic, junior engineer.

John B. Knaebel was recently appointed assistant to the vice president, The Anaconda Co., with headquarters in New York. A graduate of Stanford University, Mr. Knaebel has been managing Anaconda's uranium operations in New Mexico since 1951.



R. W. DIAMOND

R. W. Diamond has accepted the presidency of the Sixth Commonwealth Mining and Metallurgical Congress, meeting in Canada next year. His duties will be to direct a nationwide organization appointed to plan and prepare for the conference. Among the plans already laid is a cross-country inspection tour of Canadian mining operations. Congress meetings will be held in eight cities, starting in Vancouver, B. C., on September 8, 1957.

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**David D. Baker** has been appointed director of the mining division, Grand Junction Operations Office, U. S. AEC, Grand Junction, Colo. Formerly associated with the Utah Construction Co., he joined the AEC staff in 1954.

**Manuel Neues Ferro** is mining and geological engineer, Societé des Mines da Borralha, Braga, Portugal.

**Lute J. Parkinson**, head of the department of mining engineering, Colorado School of Mines, is on a European lecture tour under the Denver Il Cirolo Italiano exchange program. He will deliver a lecture series at the University of Bologna and three other Italian mining schools, do research in Italian mining methods, and give a few additional lectures in Germany.



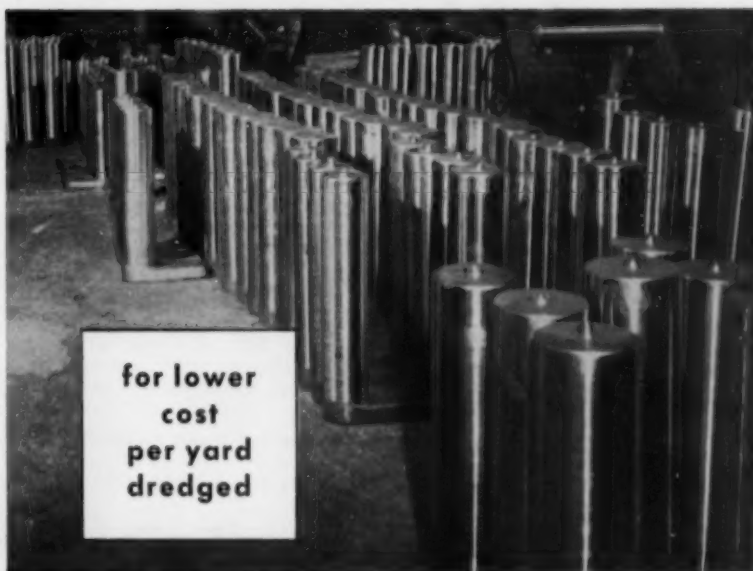
L. J. PARKINSON

**Robert J. Linney** has been elected vice president in charge of operations, Reserve Mining Co., Duluth. A former manager of mining properties for Republic Steel Corp., he joined Reserve in 1950. Mr. Linney is an alumnus of Worcester Academy and Yale University.



R. J. LINNEY

**W. A. Griffith** has been promoted from assistant mill chief to chief of milling and maintenance, Bertha Mineral Div., The New Jersey Zinc Co., Austinville, Va.



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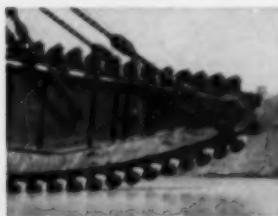
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**Robert F. Winkle** has been promoted to mine planning engineer, Ray Mines Div., Kennecott Copper Corp., Ray, Ariz.

**A. L. Hayes, R. E. Radabaugh, and K. C. Apland** have been transferred to the uranium operations of Texas-Zinc Minerals Corp., Mexican Hat, Utah. Mr. Hayes will act as manager, Mr. Radabaugh will direct mining operations and Mr. Apland will be mill chief of the new enterprise.

**Lloyd T. Buell** is project auditor, Leavell & Ponder Co., Abilene, Tex.

**James D. Mancuso** has joined Bear Creek Mining Co., Minneapolis.

**James A. Ross** has assumed chairmanship of the board at Sprague & Henwood Inc., and **Adrian E. Ross** has become company president.

**A. J. Keast**, managing director of Rio Tinto Construction & Development Co., Australia, has been awarded an honorary Doctor of Engineering degree by his alma mater, Michigan College of Mining and Technology.

**John H. Lucas** has left Ray Mines Div., Kennecott Copper Corp., to become quarry engineer and assistant quarry superintendent at Permanente Cement Co., Lucerne Valley, Calif.



**R. W. NEYMAN**

**Ralph W. Neyman** has been named president and chief executive officer of Federal Uranium Corp., Salt Lake City. The appointment followed Mr. Neyman's resignation from Hecla Mining Co., of which he had been general manager since 1951. A self-educated mining and mechanical engineer, he developed the Neymatic car, an automatic dump car operated by photo-electric eye; a turntable for underground slushers; an automatic transfer system for underground ore cars and trains; a one-man mucking machine; and other mining equipment. He is also the author of numerous technical articles on mining operations.

**Earl V. Ackerlow** has been appointed assistant division manager, Engineering Dept., Kaiser Engineers. In this capacity he will be responsible for coordinating the engineering of Kaiser Steel's expansion program at the Fontana, California plant.

**Julian Tobey** president, Appalachian Coals Inc., has been elected to the board of directors of the Air Pollution Control Association.

**Thomas W. Mitcham**, who resigned as exploration manager, International Ranwick Ltd. has opened consulting offices in Flagstaff, Ariz.

**B. J. Hamilton** is now operations manager for all the Hochschild mining interests in Southern Peru.

**Paul W. Allen** is vice president and general manager, Pima Mining Co. of Cyprus Mines Corp., Tucson, Ariz.

**Edward Matsen** has left Maraman & Co. for the Philippine Iron Mines, Camarines Norte, P. I.

**Morton E. Pratt**, formerly mine superintendent, Keystone Unit, American Smelting & Refining Co., is now assistant general superintendent, Utah Construction Co., Cedar City.

**Abraham Dor** has returned from Tel Aviv where he was chief engineer for Israel Mining Industries, to accept an assignment as project engineer, Bechtel Corp., San Francisco.



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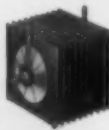
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G. B. BLONSKY

**George B. Blonsky** is acting as project engineer for the fertilizer plant which F. H. McGraw & Co. is building in Korea. His headquarters will be in the company's N. Y. office.

**John Eliot Allen** has been appointed professor of geology at Portland State College, following four years' work as economic geologist with the New Mexico Bureau of Mines and Mineral Resources. Dr. Allen, who received a Ph.D. from the University of California, is a fellow of the Geological Society of America and author of numerous bulletins and papers on areal geology and minerals.



W. A. MUDGE

**W. A. Mudge** has been appointed special representative on educational programs, International Nickel Co. of Canada Ltd. and its U. S. subsidiary, International Nickel Co. Inc. Dr. Mudge had been director, Technical Service Section, Development & Research Div. since 1947. He joined INCO in 1920.

**Earle M. Bagley, Jr.**, is the new superintendent of raw materials, Calaveras Cement Co., San Andreas, Calif. **Edgar Andersen** has succeeded him as assistant quarry superintendent.

**Ronald Nadler** is now associated with Titanium Metals Corp. of America, Henderson, Nev.

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## OBITUARIES

### Arthur Lucian Walker, Jr.

An Appreciation by  
Edward C. Meagher

Arthur Lucian Walker, Jr. died unexpectedly at Doctors Hospital in N. Y. on August 7. Apparently in good health, he had entered the hospital that morning for a periodic check up.

He was born in Baltimore, June 10, 1898, the son of the late Professor Arthur L. and Laurie McNair Walker. His father's prominence in metallurgy directed his interest to the mineral field, and to a bachelor's degree at Columbia University in 1921 with a major in mining and metallurgy. His extra-curricular activity, golf, was of such caliber as to win for him the inter-collegiate championship.

After graduation he turned his interest to Wall Street and to investment firms concerned largely with mining securities. His associations with his father and his visits to many mining districts as security analyst, together with his activities in the AIME, resulted in a wide acquaintanceship among both the operating and the administrative personnel of the mining industry.

In 1938 "Luce" Walker joined Texas Gulf Sulphur Co. At his

death he was assistant sales manager, dealing mainly with exports.

A very active member of AIME, he served successively as secretary and as committeeman of the New York Section, and for many years no Annual Meeting of the Institute in New York was complete without him as chairman or vice-chairman of an important arrangement committee. Luce Walker and his charming wife Henrietta contributed greatly to the success of the social events of many of the February Meetings. Her death in 1946 created a tremendous void in his life.

He had great capacity for making friends, a quiet dignity and an old fashioned courtesy that were refreshing. In all, he was a very worthy son of his distinguished father, and his untimely death left a place in the lives of his friends and associates that will be extremely difficult to fill.

### Alexander J. McNab

An Appreciation by  
H. DeWitt Smith

Alexander J. McNab (Member 1916) died at his farm at Pine Plains, New York on July 4, 1956 at the age of 78. Born in Glengarry County, Ontario in 1877, he graduated from Queen's University, Kingston, Ontario in 1902 with degrees of B.A. and B.Sc., and fifty years later was honored by his university with the honorary Doctor of Laws.

After graduation, Mr. McNab went to work in the metallurgical department of Canadian Smelting Works, predecessor to Consolidated Mining & Smelting Co. of Canada Ltd., at Trail, B. C., where he was soon placed in charge of a Betts electrolytic plant for recovery of lead. In 1911 he went to Mason Valley, Nev. for the W. B. Thompson interests, with which Mr. McNab was intimately associated for the rest of his career. When Mason Valley closed down in 1915, Mr. McNab joined Newmont Mining Corp. with headquarters in N. Y. C. and served as a director from 1931 to 1948. During his association with Newmont he was intimately involved in the development of the Rhokana Copper property in Northern Rhodesia, O'okiep Copper Co. Ltd. and Tsumeb Corporation Ltd. in South and South West Africa respectively, and of Hudson Bay Mining & Smelting Co. Ltd. He was a director and officer of the latter three companies for many years, and his advice was invaluable in their original construction programs and rapid expansion.

In 1920 Mr. McNab became vice president of Magma Copper Co. in charge of operations and maintained the direction of that company for the balance of his life. His guidance of these operations from the viewpoint of technical, financial and labor relations has been a masterpiece, with work quietly, effectively

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## Necrology

Date Elected	Name	Date of Death
1935	W. H. Burke	July 31, 1956
1909	Edwin J. Collins	Aug. 15, 1956
1919	O. J. Eggleston	Aug. 23, 1956
1947	Ralph H. Espach	Aug. 6, 1956
1917	M. B. Gentry	July 31, 1956
1920	Neil M. Gibson	July 10, 1956
1952	A. E. Harris	October 1955
1938	Morton T. Higgs	June 1956
1904	Edwin W. Mills	Unknown
	Legion of Honor	
1955	Charles G. Penland	Unknown
1921	Paul H. Reisher	Dec. 22, 1955
1936	Arthur L. Walker, Jr.	Aug. 7, 1956
1936	A. W. Walker	July 19, 1956

and wisely performed. He was directly responsible for the acquisition of the San Manuel property by Magma, and for the completion of this \$125,000,000 enterprise within cost and time estimates. Time after time it appeared that the great capital requirements of San Manuel could not be raised, but with Scotch grit and courage, Mr. McNab saw this program through, aided by a small and highly competent staff.

Sandy McNab will be sorely missed by all those who knew and worked with him, for his farsighted and clear vision, his stout courage in face of difficulties and discouragement, and for the deep personal affection which he inspired.

**Martin B. Gentry** (Member 1917) died in Southern Pines, N. C. at the age of 69, after a long illness. A native of Kansas City, Mr. Gentry received his education at Yale and the Columbia School of Mines, from which he obtained a degree in mining engineering in 1909. His earliest mining experience was gathered in Arizona in the employ of Tombstone Consolidated Mines Co. Moving on to South America, he engaged in scouting and exploration for the Chile Exploration Co. and later worked in Brazil and Bolivia. Following World War I, during which he served as captain, Army Engineer Corps, Mr. Gentry represented Anaconda Copper Mining Co. in Santiago, Chile. Between 1927 and 1935, he held various positions in N. Y. with Allied Chemical & Dye Corp., Solvay Process Co., and the Beryllium Co. of America. Mr. Gentry joined the staff of Freeport Sulphur Co. in 1935 as assistant to the president, and was named vice president in 1941, serving in that office until his retirement in 1949. He was vice president and treasurer of the American Arbitration Assn. and past-president of the Mining & Metallurgical Society of America and the Mining Club of N. Y.

## MEMBERSHIP

Proposed for Membership  
Mining Branch, AIME

Total AIME membership on Aug. 31, 1956 was 28,451; in addition 2,839 Student Associates were enrolled.

## ADMISSIONS COMMITTEE

R. B. Caples, Chairman; F. A. Ayer, Vice-Chairman; A. C. Brinker, R. H. Dickson, C. R. Dodson, R. B. Fulton, T. D. Jones, F. W. Hanson, Sidney Rolfe, F. T. Staco, O. B. J. Fraser, F. W. McQuiston, Jr., A. R. Lytle, L. P. Warriner.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

### Members

John P. Burke, Phoenix, Ariz.  
Vernon Camp, Lone Star, Texas  
James M. Clements, Lone Star, Texas  
G. P. Decker, Monticello, Utah  
T. M. Howell, Little Rock, Ark.  
Allan E. Jones, Grand Junction, Colo.  
E. F. Kindsvater, Carlsbad, N. M.  
D. Morris, Kotliakumbura, Ceylon  
Warren M. Peterson, Rialto, Calif.  
Edwin J. Poehlmann, St. George, Utah  
L. A. Smith, Palo Alto, Calif.  
William Lee Smith, Columbus, Ohio  
Darwin Soler, Oriente, Cuba  
Andrew L. Stewart, Nairobi, Kenya  
James B. Studebaker, Denver  
R. R. Taylor, Copper Cliff, Ont., Canada

### Associates

Raymond W. Foulke, Jr., Dallas, Pa.  
Edward W. Dolch, Mt. Vernon, Wash.  
Joseph F. McDonald, Jr., Las Vegas, Nev.  
G. C. Seward, New York

### Juniors

Harry A. Astlett, New York  
K. J. Conway, Queensland, Australia  
Egmont W. Cronau, New York  
Jack S. Diskin, Grand Junction, Colo.  
Paul A. Head, Jerome, Ariz.  
R. J. P. Lyon, Salt Lake City  
Carlos H. Tiernon, Fort Wayne, Ind.  
J. L. Vannoy, Austinville, Va.

### CHANGE OF STATUS

#### Associate to Member

K. R. Fleischman, Suva, Fiji  
Durward C. Spees, Rosiclare, Ill.  
John S. Sumner, Minneapolis  
Jay Tuttle, III, Rialto, Calif.  
Leroy Wm. Weeks, Riverside, Calif.

#### Junior to Member

Rixford A. Beals, Oceanside, N. Y.  
Wm. H. Sutherland, Holden, W. Va.

#### Student to Junior

Richard W. Ziminski, Jefferson City, Tenn.

### REINSTATEMENT

#### Members

James A. Bradbury, Forty-Fort, Pa.  
Frank D. Lamb, Bladensburg, Md.

### REINSTATEMENT—CHANGE OF STATUS

#### Student to Member

George R. Eadie, Champaign, Ill.  
Edwin B. King, Silver Bell, Ariz.  
L. E. Mannion, Berkeley, Calif.  
Robert O. Wenzel, Naturita, Colo.  
Frank E. Woodard, Grand Junction, Colo.

## Chicago ESPS Report

The Chicago office of the Engineering Societies Personnel Service Inc. has made a study recently of the registrations and job opportunities in their current or active files. This resulted in some figures of interest to the engineering and scientific professions.

The first joint effort of the Engineering Societies to establish an employment office was in 1918. The management was taken over in 1923 by the Founder Societies—AIME, AChE, ASME, and AIEE, and the Boards of Direction inaugurated a new policy respecting the Employment Service. The Service was confined to members of the four National Societies and cooperating organizations until 1929, when it was felt that more effective service could be rendered by offering it to non-members at a higher charge. Offices were soon established throughout the country. The Chicago office, opened in 1925, was administered by representatives from the sections of the Founder Societies in Chicago, in cooperation with the Western Society of Engineers, which also gave financial support.

Since the first of the year, the Chicago office of the ESPS has averaged better than two and one half job opportunities for every man registered. This indicates that it is the ideal time for any person seeking new or better employment to register with the Chicago office.

Of the jobs studied, 44 pct were at salaries of \$7000 a year and lower; 44 pct at salaries ranging from \$7000-\$10,000 a year; and 12 pct over \$10,000 a year. The heaviest demand, 44 pct of the jobs, is in a range where only 21 pct of total applicants are available. Only 25 pct of the employers still expect the applicant to pay his own fee.

Taking the above figures into consideration, the Chicago office of ESPS requested the National Board of Directors to grant permission for conversion to the 100 pct Employer Pays Fees Plan. Approval was granted, and the conversion will soon be complete.

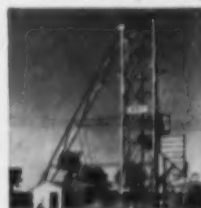


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## Coming Events

- Oct. 11-13, University of Minnesota, Annual Drilling Symposium, Center for Continuation Study, University of Minnesota, Minneapolis.
- Oct. 22-24, ASA, 38th annual meeting, Hotel Roosevelt, New York.
- Oct. 24, AIME, Black Hills Section, annual meeting and visit of AIME President-Elect Grover J. Holt.
- Oct. 25, 26, AIME-ASME Joint Solid Fuels Conference, Future Role of Solid Fuels in an Expanding Economy, Sheraton-Park Hotel, Washington, D. C.
- Oct. 25-26, ECPD 24th Annual Meeting, Engineering Society of Detroit, Statler Hotel, Detroit.
- Oct. 29-31, First Annual Energy Resources Conference, Cosmopolitan Hotel, Denver.
- Oct. 29-Nov. 1, Society of Exploration Geophysicists, 26th annual meeting, Hotel Roosevelt, New Orleans.
- Oct. 31-Nov. 3, Gulf Coast Assn. of Geological Societies, sixth annual convention, Plaza Hotel, San Antonio, Texas.
- Nov. 1-3, Geological Society of America, annual meeting, Minneapolis.
- Nov. 1-3, New Mexico Mining Assn. and International Mining Days, Carlsbad, N. M.
- Nov. 5, AIME, Pittsburgh Local Section, NOHC Pittsburgh Local Section, annual off-the-record meeting, William Penn Hotel, Pittsburgh.
- Nov. 5-8, AIME, Central Appalachian Section and Petroleum Subsection, Fall Meeting, (Joint meeting with West Virginia Coal Mining Institute.) Greenbrier, White Sulphur Springs, W. Va.
- Nov. 8, AIME, Adirondack Local Section, football game, dinner-dance, Hotel Syracuse, Syracuse, N. Y.
- Nov. 5-7, CIM, annual western meeting, Vancouver Hotel, Vancouver.
- Nov. 8-10, AIME, Northeastern Mining Branch Conference, Hotel Hershey, Hershey, Pa. Lehigh Valley Section is host.
- Nov. 12, 13, Joint Symposium on Mining Research, Missouri School of Mines and USBM, Rolla, Mo.
- Nov. 12-13, Amer. Petroleum Inst., annual meeting, Conrad Hilton Hotel, Chicago.
- Dec. 2-7, AIME, Electric Furnace Steel Conference, Hotel Morrison, Chicago.
- Feb. 7-9, 1957, Colorado Mining Assn., Denver.
- Feb. 21-23, AIME Annual Meeting, Roosevelt and Jung Hotels, New Orleans.
- Mar. 10-16, EJC Second Nuclear Engineering and Science Congress, Convention Hall, Philadelphia.
- Apr. 1-4, Amer. Assn. of Petroleum Geologists, annual meeting, Kiel Auditorium, St. Louis.
- Apr. 5, 6, AIME Pacific Southwest Mineral Industry Conference, Sponsored by Nevada Section, cosponsored by San Francisco and Southern California Sections, Reno, Nev.
- Apr. 8-10, AIME, National Open Hearth Steel and Blast Furnace, Coke Oven, and Raw Materials Conferences, William Penn Hotel, Pittsburgh.
- Apr. 11-13, AIME, Pacific Northwest Regional Conference, Portland, Ore.
- Apr. 22-24, Second Annual Symposium on Rock Mechanics, Colorado School of Mines, Golden, Colo.
- Apr. 25-24, CIM, annual meeting, Ottawa, Ont., Canada.
- May 13-16, Coal Convention and Exposition of the American Mining Congress, City Auditorium, Cleveland.
- Nov. 11-14, 1957, Society of Exploration Geophysicists, 27th Annual Meeting, Statler-Hilton Hotel, Dallas.

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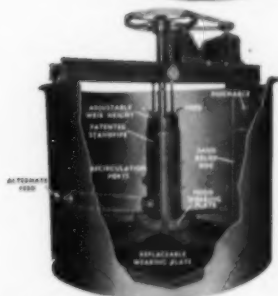
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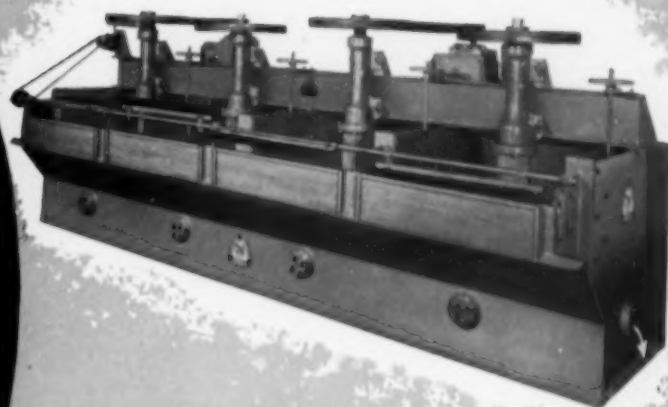
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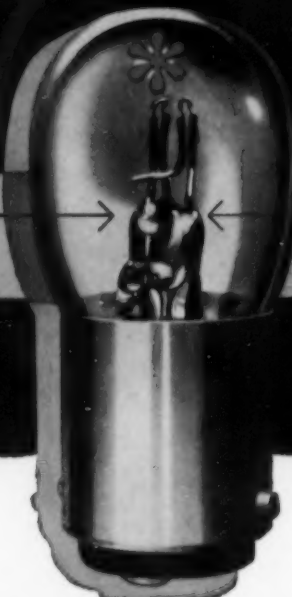
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